RESEARCH REPORT

THE EFFECT OF IMPROVING THE HOME ENVIRONMENT ON ASTHMA:

A PILOT STUDY

FINAL REPORT

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THE EFFECT OF IMPROVING THE HOME ENVIRONMENT ON ASTHMA: A PILOT STUDY

Final Report

July 1998

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EXECUTIVE SUMMARY

This research project was a pilot study to determine the effect of improving the indoor air quality (IAQ) in the home on the asthmatic condition of the occupants. The objectives of the project were to design the study to monitor the effects of the air quality of the home on asthma, to examine different ways of following the health of the asthmatic individual and to determine any housing/health correlations from an actual field study. Lessons learned from this pilot would be applied to a future larger study.

Homeowners with at least one asthmatic family member in the Ottawa-Hull area were invited to participate. Only non-smoking households without pets were considered for the study. One additional criterion was the willingness to carry out renovations to improve indoor air quality at the homeowners' expense.

Fifty respondents were interviewed by telephone and asked to complete a questionnaire about their house and the asthmatic occupant's health condition. This preliminary screening identified eleven candidates who associated the onset of asthma or the aggravation of symptoms with the house.

Each of the eleven houses was inspected following the protocol developed for CMHC's Residential IAQ Investigator Program. Ten of the eleven houses were found to have IAQ problems primarily due to molds in the basements. Some of the basements were exceedingly moldy. One of these houses had an oil spill in the basement in addition to mold problems. One house had predominantly chemical contamination from a new carpet. Remediation measures, grouped into Minimum (required for participation in the study), Recommended and Optional, were developed for each house. Cost estimates to carry out these measures were provided to the homeowners.

Six households expressed their willingness to carry out the required renovations within the time frame of the study. The asthmatic subjects included four adults, a teenager and a young child with asthma. Four control subjects (their houses were not renovated) were recruited. The participants reported aggravation of their asthma in the basement.

On the basis of the inspections, detailed specifications were developed for carrying out the renovation work. Prior to the renovation, the houses were tested for air tightness, carbon dioxide (CO_2), relative humidity, volatile organic compounds (VOCs), house dust mites, ergosterol and molds.

No correlation was found between measured dust mite levels and the reported aggravation of asthma in the basements. Lower levels of dust

mite antigens (Der f 1) in the basement compared to the main floor in two houses ruled out dust mites as the cause of the aggravation of the occupants' asthma.

The mold tests confirmed the qualitative findings of the inspections, that the basements were very moldy, and substantiated the recommended remedial steps. Air and dust samples from the basements failed the Pass/Fail criteria for contamination due to molds, and bulk samples confirmed the growth of non-phylloplane molds. All six houses had toxigenic molds. Five houses had one or both of the dangerous molds, *Stachybotrys chartarum* and *Aspergillus versicolor*. These five houses were renovated. One homeowner, unwilling to carry out more stringent remedial work dictated by exceptionally high levels of a toxigenic mold in his basement, opted out of the study.

The five houses were renovated to varying degrees of completion. Inspections of the renovation work were performed to monitor the progress and to ensure the work was carried out as specified. One house (House 3) was meticulously and thoroughly cleaned for molds, and the foundation was improved to prevent moisture entry. The air quality of this house was markedly improved, and no molds were detected on re-testing. The basements of three houses (Houses 1, 4 and 5) were cleaned, but no remedial work was undertaken to control moisture entry. The perceived air quality improved after the clean up, but mold regrowth had occurred at the end of the study. The basement of the fifth house (House 2) was only partially cleaned up. Tests showed this house continued to be highly contaminated.

Information about the health of each of the occupants with asthma was obtained through interviews, detailed questionnaires before and after renovation and by daily recording of symptoms. The participants and controls were also asked to measure peak expiratory flow rates (PEFRs).

The participants reported that peak flow measurements were not a sensitive measure of how well or poorly they were breathing. A record of how they felt, their need for medication, the frequency, severity and duration of respiratory infections and frequency of visits to their doctor was more informative than peak flow measurements.

Improvements in the asthma condition of the occupants correlated with the degree of improvement of the air quality of the house. Both daughter and mother in House 3 experienced significant improvement of asthma and chronic fatigue symptoms, respectively, after the renovation. The adult asthmatics of Houses 4 and 5 reported marked improvement and no longer needed medication half a year to nine months after the renovation. The adult asthmatic of House 1 did not find any improvement. The asthma of the owner of House 2 became worse while he gutted his basement. The control subjects did not report an improvement during the study period.

The results of this pilot study suggests a need for a larger study involving participants who can demonstrate commitment for complete, rather than partial, remediation.

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PREFACE

There is a consensus that poor indoor air quality in housing is linked to the health of the occupants. The mechanism leading to disease is understood for very few indoor contaminants. Typically, disease-pollutant associations are obtained from surveys of populations exposed to the pollutant.

Surveys conducted in different countries have indicated that dampness and molds in houses are linked to respiratory health. It is important for everyone, particularly the increasing number of people who suffer from asthma, to understand the extent poor indoor air quality in the home contributes to health. To encourage people to renovate their homes for health, convincing evidence of the health benefits of improved air quality is needed. Research for the purpose of collecting such evidence is desirable.

An intervention approach was selected for this pilot study. Several households with one or more asthmatic family members who live in houses that have poor indoor air quality were invited to participate. The homeowners were provided expert advice on how to renovate their homes. The renovation provided an opportunity to monitor the health of the asthmatic individuals.

CMHC conducted this study with Drs. R. Dales and J. Leech, Health Canada researchers and respirologists, and with Dr. J. D. Miller, mycologist. Drs. Dales and Leech collaborated with CMHC in the design of the health measurements, while Dr. Miller assisted in the interpretation of the mold findings. CMHC contracted the field measurements and preparation of the report to Buchan, Lawton, Parent Ltd, an engineering firm.

It is important to note that this pilot study involved only a handful of houses. The health outcomes from the small sample cannot be generalized. There is a need for a larger study to look at a wider variety of asthmatic individuals and houses.

I wish to thank the families who gave their time and resources for this study. The asthmatic participants are pioneers — they were willing to be involved in the pilot not only for themselves but also for other asthma sufferers.

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1. INTRODUCTION

Asthma and other forms of lung disease affect approximately twenty percent of the population in Canada. Empirical evidence indicates a relationship may exist between the health of patients with lung disease and the quality of air in their homes. Incidents have been reported of asthma problems first occurring when a person moves into a home or carries out a renovation project. As well, improvements to health have been noted when the air quality in a person's living environment has been improved.

Generally the reports relating indoor air quality problems and lung disease have been anecdotal. One asthma sufferer, for example, reported "feeling better" after the old shag carpet was removed from the bedroom and living room and the original hardwood floors were refinished. In another case, a child "developed" asthma symptoms shortly after a basement renovation was carried out.

Indoor air quality researchers have long believed that improvements to the indoor air quality in the home can have a positive impact on the health of the occupants.

This pilot research study on housing and asthma attempted to establish whether a correlation could be documented between indoor air quality problems and asthma. The objectives of the study were to:

- design a study to monitor the effects of improving the indoor air quality of the home on asthma;
- examine different ways of following the health of the asthmatic individual;
- find out if any housing/health correlations were indicated by this pilot study; and
- estimate the level of effort of carrying out a larger study.

The goal of the research project was to answer the question: Could improvements in the air quality in the home result in improvements to the health of the asthma sufferer?

To obtain empirical evidence to answer the question, detailed monitoring was required of the health of a person before and after carrying out renovations to improve the indoor air quality in a house along with detailed air quality investigations. Monitoring and analyzing indoor air quality parameters is an expensive undertaking, as is identifying and specifying remedial measures to improve indoor air quality. For these reasons, the pilot study focussed on an intensive investigation of a small number of homes.

The pilot research study involved:

- identifying six households to participate in the study and convincing the participants of the value of carrying out renovations to improve the indoor air quality in their home at their expense;
- assessing the state of the indoor environment in each house prior to carrying out the renovation work;
- obtaining health information from the occupants with asthma prior to the renovation work;
- developing the specifications for the renovation work and performing random inspections of the clean up and renovation work;
- assessing the state of the indoor environment after the completion of the renovation work;
- obtaining health information from the occupants with asthma after the completion of the renovation work; and
- documenting the study.

2. SCREENING THE PARTICIPANTS AND THEIR HOUSES

In January 1997, advertisements were placed by CMHC in the Ottawa Citizen and *Le Droit* advertising the study. Two requirements were stated up front — participants must be non-smokers and have no pets. These requirements were included to avoid the confounding factors that pets and smoking would introduce to the study. Over the course of two weeks, more than 50 people responded to the advertisement and expressed an interest in participating in the study.

A short, two-page questionnaire was used to document each respondent. The questionnaire asked about the health problems experienced by the caller or other occupants of the house, the likelihood of the problems being related to living in the house and the willingness of the owners to carry out renovations at their expense to improve the indoor air quality in their home.

Participants in the project were also sought through contacts of the CMHC Research Authority, the project team and with doctors in the Ottawa-Hull area.

Despite the offer of a free indoor air quality investigation, free engineering work and IAQ testing before, during, and after the remedial work, many of the callers were unable or unwilling to commit to carrying out any renovations on their homes. A number said they would move before they would undertake any renovations. Other callers did not appear to have asthma problems related to their living environments.

In the final outcome, 11 candidate houses were identified in the Ottawa-Hull area. The houses included single family homes and a semi-detached house, ranging in age from over 90 years to less than 15 years old. All had been occupied for more than one year by the person with asthma and all were occupied by their owners. In the next stage of the study, these houses were subjected to further screening. Six houses were ultimately selected from the pool of eleven for participation in the study.

3. FINAL SELECTION OF SIX HOUSES FOR PILOT STUDY

Each of the 11 houses was visited and the occupants were interviewed. A preliminary investigation was conducted to assess indoor air quality problems, gather information about the asthmatic person's health and determine the homeowner's willingness to undertake renovations, as well as, their willingness to participate in the study.

More specifically, the detailed inspections of these houses included:

- sending a detailed questionnaire to the asthma sufferers to obtain information about themselves, their medical problems and their house;
- conducting an indoor air quality inspection using the protocol developed for the Residential Indoor Air Quality Investigator Program;
- preparing a preliminary list of remediation strategies and establishing the priority for undertaking the work;
- developing estimates of the costs to carry out the proposed remediation work; and
- establishing a preliminary schedule for the monitoring and renovation of each of the houses.

The inspection followed the protocol developed for the Residential Indoor Air Quality Investigator Program. The protocol consisted of a walk through the house and, based on the collected observations, identified sources of the IAQ problems and solutions to these problems. Analytical tests for contaminants were not carried out in the initial inspection.

From the preliminary investigations, a list of suggested remediation measures was developed including cost estimates.

Table 3.1 contains a summary of the findings of the indoor air quality investigation for the 11 houses. A house-by-house compendium of the findings is presented in Appendices A and B. Appendix A contains the summaries of Houses 1 to 6 — the houses ultimately chosen for further investigation and remediation work. Appendix B contains the summaries of Houses 7 to 11.

All of the 11 houses met the criteria for participation in the study. Each house was occupied by a person with asthma, was smoke free and had no pets. Each house had indoor air quality problems and solutions could be identified to address the IAQ problems. The findings of the preliminary investigation was communicated to each of the homeowners.

The indoor air quality problems in ten of the 11 houses were predominantly related to molds. This was in keeping with the findings from a previous study[1] where molds were identified as the most prevalent source of the indoor air quality problem. The exception was a house with a new carpet in the basement. Another house had an oil spill in the basement in addition to mold problems.

Five of the 11 houses were eliminated. Four of the homeowners indicated an inability to carry out the proposed renovations in the time frame required for the study. One indicated a willingness to carry out only a portion of the required renovations. Before the first phase of the testing could be carried out, one of the homeowners acted on one of the preliminary recommendations of the investigation. A ventilation system was installed in the house in a way that would not provide the best benefit to the occupant with asthma.

The six remaining houses were all chosen for continuation in the study and the detailed indoor air quality investigation. They were chosen based on the homeowners' determination to improve the air quality in their home, a strong housing/asthma connection as reported by the asthma sufferer and demonstrated willingness to co-operate with the study and carry out the renovation project.

Two control houses were selected from among the five eliminated houses. As well, two other control houses were obtained from participants who volunteered. In two of the control homes, dust mite tests were taken in the basement and living room, vacuum dust samples were taken and analyzed for molds and one set of air samples were taken.

Table 3.1
Summary of the Indoor Air Quality Investigations of 11 Houses

House No.	1	2	3	4	5	6	7	8	9	10	11
Number of Occupants	2 adults, 2 children	2 adults	2 adults, 1 child	2 adults	2 adults, 2 children	2 adults, 2 children	3 adults	2 adults, 2 children	2 adults, 2 children	2 adults	2 adults 2 children
Health Problems	48 yr old female – asthma +	44 yr old male – asthma	4 yr old child – asthma, and mother has allergies	38 yr old female – asthma	39 yr old female – asthma	15 yr old female – asthma	56 yr old female – asthma	45 yr old female – asthma +	44 yr old female & 12 yr old son – asthma +	74 yr old female – asthma	8 yr old son – asthma
Allergies to	dust, molds, chemicals, etc.	perfume, dust, etc.	food & environment	pesticides, coal/oil dust, etc.	dust, molds, grasses, smoke, etc.	dust, feathers, cats, etc.	dust, molds, pollen, etc.	dust, molds, pollen, etc.	chemicals, smoke, etc.	dust, chemicals, smoke, etc.	dogs, cats, molds, dust, weeds, etc.
Age of House	1930s	1980s	1955	before 1930	1920	1946	1941	1966	1967	1940s	1969
Type of House	3-storey detached	detached bungalow	detached bungalow	2-storey, semi-detached	3-storey masonry	2-storey masonry, detached	split level detached	high ranch bungalow	2-storey detached	detached bungalow	detached bungalow
Foundation	concrete – basement & crawlspace	concrete – basement	concrete – basement	concrete – basement	rubblestone – basement, crawlspace	concrete – basement & crawlspace	concrete – basement & crawlspace	concrete – basement	concrete – basement	concrete/ brick – basement	concrete – basement
Heating System	forced air oil, electric baseboards	electric baseboard	forced air electric heating system	forced air	hydronic natural gas-fired, wood-burning fireplace	forced air	forced air gas, fireplace	forced air electric	forced air oil, fireplace	forced air & air conditioned	electric baseboard heating
Window Use	open year round	summer	slightly open year round	summer	open year round	open year round	open year round	slightly open year round	open year round	open year round	weekly year round
Condensation on Windows	occasional – basement, bathrooms	frequent	frequent		frequent		frequent in winter	occasional on walls	occasional in winter	occasional in winter	frequent
Cold Spots, Drafts	yes	yes	yes	yes	yes	yes	attic hatch	basement	yes	unknown	unknown
Carpeting	extensive	extensive	some	some	some	some	some	some	extensive	extensive	+ 50%
Use Scented Products	yes	yes	yes	yes	yes	yes	yes	no	no	yes	yes
Store Items in Basement	yes	yes	yes	yes	yes	yes	yes	yes	yes, not damp	yes	yes

Table 3.1
Summary of the Indoor Air Quality Investigations of 11 Houses (Continued)

House No.	1	2	3	4	5	6	7	8	9	10	11
Major Concerns	• molds in basement • carpets upstairs • lack of ventilation • possible water infiltration through basement walls	• severe molds • lack of ventilation	• molds in basement • lack of ventilation • water leaks • contaminant sources	• molds • dampness in basement • dirt in ductwork	• molds in basement • lack of ventilation	• moisture entry into house from grounds and roof • molds in basement • air above earth floor in crawl space entering house	• high moisture levels • molds/ crystals in basement	• molds in basement • high moisture levels • insufficient ventilation	• chemical contamination • minor mold • ventilation	• oil spill '96 • long-term mold problems • poor ventilation	• molds in basement • lack of ventilation
Other Concerns Noted							• flagstone floor in crawl space		• odours from garage smelled in house		
Minimum Remediation	• clean up clutter in basement • clean basement walls and ceiling with bleach • foam penetrations through walls • paint concrete floor • excavate around exterior of house • install HRV	• gut basement • clean all surfaces with bleach • excavate around exterior • replace HRV	• rectify sewer drain pipe problem • gut, clean and seal basement • clean up and minor repairs • clean mold from window frames • remove carpet from dining room • install HRV • regrade yard	• clean up basement • vent dryer outside • foam all penetrations in walls & floors • airseal and clean ducts • install HRV	• gut and clean basement • clean or replace damaged hardwood floor • install HRV • clean up and minor repairs • regrade yard • replace gas stove	• fix crawl space • clean up • improve grade of slope away from house • install HRV • remove or replace carpeting	• regrade around house • pour concrete floor in crawl space • clean up clutter & do minor repairs • install HRV • remove main floor wallpaper	• gut & clean basement • clean up clutter & do minor repairs • regrade around house • install HRV	• clean up clutter & do minor repairs • clean basement • airtighten house • remove carpets • install HRV	• remove oil soaked concrete and soil • clean up clutter • clean basement • cover sump pit • remove carpets • install HRV	• clean up clutter • gut, clean basement, sump pit • install drainage around house perimeter • remove particle board furniture • install HRV

4. INDOOR AIR QUALITY TESTING — RATIONALE AND PROCEDURES

Various tests were conducted to measure the presence of molds, fungi and other contaminants in each of the six houses. Air samples, material samples, dust samples and surface wipes were gathered and analyzed to determine the quality of the air in each home and to identify any problem areas.

The location and type of the tests were chosen based on the findings of the preliminary investigation and following the protocol developed by the CMHC Research Authority and Buchan, Lawton, Parent Ltd. This section outlines the range of tests carried out, the typical testing locations and discusses the thresholds at which the readings were considered to be a concern.

Appendix C documents the procedures followed by the laboratories to analyze the various samples collected under the study.

Carbon Dioxide

Carbon Dioxide (CO_2) testing was carried out over a two-day period using a Progeco tech PL-CO_2 gas monitor. The monitor was placed in the master bedroom of each of the houses. The level of CO_2 in the air was sampled every 20 seconds. The highest level of CO_2 detected over the two-day period was used as the reading recorded in the study.

The average background level of CO_2 in outdoor air is 340 ppm. Indoor levels tend to be higher than outdoor levels. According to Health and Welfare Canada[2], readings above 600 ppm have been associated with complaints about stuffiness, headaches, fatigue, unpleasant odours and undue warmth. Readings over 1,000 ppm in non-residential settings are indicative of an inadequate supply of fresh air and, therefore, an indicator of inadequate ventilation. From the point of view of human health[3], the acceptable long-term exposure range for CO_2 in residential indoor air is 3,500 ppm.

Sources of CO_2 include human respiration, combustion engines and combustion appliances, such as kerosene heaters and oil and gas furnaces. Significant reductions in CO_2 levels are usually achieved by increasing the ventilation.

Volatile Organic Compounds

Volatile organic compound (VOC) testing indicated the presence of chemical compounds in the indoor air. It can also be used as an indicator of some fungal activity. One air sample was taken in the basement of each home during the initial testing. A 3M adsorbent charcoal tube was used in a 3M *3,500 OVM* (organic vapour monitor) to obtain air samples for the VOC analysis.

In most cases, the laboratory analysts were able to identify the various parameters of the VOCs within the sample. This provided information as to the potential sources of the VOCs.

Table 4.1 lists some common volatile organic compounds and their potential sources.

Miller et al., discussed the concept of total volatile organic compounds (TVOC) in their examination of fungi in Canadian homes. Health complaints were associated with TVOC values in excess of 2 mg/m^3.

Relative Humidity

Relative humidity and temperature measurements were used to document the ambient conditions in the houses. Spot measurements were taken in the basement and on the main floor of the houses using a power psychrometer before and after the renovations were carried out. Readings outside of the accepted norms of 30 to 80% RH in the summer and 30 to 55% RH in the winter[5] were identified as being a concern.

Table 4.1
Typical Sources of VOCs

VOC	Typical Source
alpha-Pinene	terpene compound used in air fresheners and in cleaning products as a fragrance enhancer
1-Chloro-1, 1-difluoroethane	aerosol propellants
Carene and 3-Carene	terpene compound used in air fresheners and in cleaning products as a fragrance enhancer
Chlorofluorocarbons	used as refrigerants, aerosol propellants
Dichlorodifluoromethane	
Ethylbenzene	petroleum hydrocarbon distillates found in fuels, solvents, cleaning products
Hydrocarbon	petroleum hydrocarbon distillates found in fuels, solvents, cleaning products
Limonene	terpene compound used in air fresheners and in cleaning products as a fragrance enhancer
Saturated Hydrocarbon	petroleum hydrocarbon distillates found in fuels, solvents, cleaning products
Tetrachloroethylene	chlorinated solvent used for dry cleaning and as an industrial degreasing solvent
Tetramethylbenzene	petroleum hydrocarbon distillates found in fuels, solvents, cleaning products
Toluene	petroleum hydrocarbon distillates found in fuels, solvents, cleaning products
Trichlorofluoromethane	
Trimethylbenzene	petroleum hydrocarbon distillates found in fuels, solvents, cleaning products
Xylene	petroleum hydrocarbon distillates found in fuels, solvents, cleaning products

Mold Sampling and Analysis

Ergosterol

Ergosterol concentration can be used as an indicator of fungal biomass and as a determinant of fungal activity[6] in the indoor environment.

For this study, filter cassettes were exposed to the air in the basement or laundry room of the house and analyzed by the laboratory. The lower detection limit for ergosterol was 0.1 ug/m^3.

In studies conducted by Miller et al.[7] a strong correlation was observed between ergosterol levels in house dust and colony forming units (CFU) of fungi in dust and air in problem homes. The levels of ergosterol increased in a 1:1 ratio with the CFUs. The authors concluded that elevated levels of ergosterol were indicative of elevated levels of CFUs in the indoor environment.

Air Samples

The spores from molds and fungi suspended in the air of the houses are considered to be an effective indicator of indoor air quality problems. Air samples were taken using a Biotest RCS-232 Air Sampler in a number of locations throughout each house. The sampling locations included the living area, kitchen, upstairs bathroom, one or two bedrooms, two locations in the basement and one outside the house. A control (blank) was analyzed for each house.

Additional air samples were taken immediately after the air leakage testing of the house. Air leakage testing disturbed the air in the house and tended to be an effective mechanism for stirring the air.

The RCS is a centrifugal sampler in which air from the room is passed over an agar medium by a spinning impeller blade for a specified period of time. For the purposes of this study, the agar strips were exposed for four minutes, then sealed and refrigerated until delivery to the laboratory within 24 hours.

As discussed in various locations in the literature, the thresholds at which the air sampling results are considered to be a concern vary significantly depending on the type of fungi identified, the diversity of molds and the count of colony forming units[8,9]. Small numbers of toxigenic[10]

fungi are of far greater concern than a large number of CFUs of one non-toxigenic fungi. Some species of fungi, such as *Cladosporium*, *Alternaria* and *Aureobasidium*, are commonly found in outdoor air[11]. The occurrence of these fungi in the indoor air can often be related to their existence outdoors rather than an indoor source.

Dust Samples for Mold Analysis

Homeowners were asked to install a new bag on their vacuum cleaner and vacuum the entire house. The bag was to be filled to at least half full to get as complete a cross-section of the dust in the house as possible. The vacuum cleaner bag was sent to the laboratory for analysis.

Currently there are no standards or guidelines for determining acceptable thresholds for molds and fungi found in dust samples. When examining the results of the analysis, the information was compared with the results from other sampling methods to identify whether any different molds or fungi existed in the vacuum cleaner dust.

Bulk Samples

Bulk samples, such as small pieces of carpet, vinyl tiles, cardboard boxes, wood and insulation, were taken and analyzed. In most cases, mold was visible on the sample or the material was suspected of contamination. The samples were removed from their location, placed in a zip-lock bag, labelled and delivered to the laboratory for analysis.

For bulk samples, the number of "+'s" indicate the relative growth of the species identified. No +'s indicate that there was little growth and +++++'s indicate the maximum growth in the opinion of the analyst.

As with the dust samples, no guidelines or standards exist for determining acceptable levels of molds or fungi in the sample. Comparing the microbial concentrations and types of microbes with the results of the air analyses and other results would help to ascertain whether the mold or fungi were growing on the bulk sample.

Slide Samples

In situations where a mold or "fuzzy growth" was visible but it was not possible to take a bulk sample, a slide or swab sample was taken. In the case of slide samples, a piece of transparent tape was placed over the mold and used to transfer the sample to a microscope viewing slide.

Swab Samples using Culturette Tubes

As with slide samples, taking a swab can be a useful method to locate sources of microbial growth. Generally, swab samples were only taken from hard surfaces. A known area of surface was wiped with a sterile swab and the swab was then inserted in a culturette tube and delivered to the laboratory for analysis.

For the swab samples, the number of "+'s" indicate the relative growth of the species identified, where one + indicates that there was little growth and five +'s indicate maximum growth in the opinion of the analyst.

Again there are no standards or guidelines for evaluating surface wipe samples. Yang[12] suggests that if the results of the analysis have few types of microbes (usually no more than three types) and each type has high colony counts, the results suggest growth of these microbes. If the results have many microbial types (usually more than five) and each type has few colonies, the results suggest dust particles that are no longer growing.

House Dust Mite Allergen

Allergies to the feces of dust mites are one of the most common types of allergies in humans. Two samples of dust were taken in each house and analyzed for dust mites. Generally the samples were taken from the bed and pillows of the person or persons suffering from asthma and in the basement carpet or another area where the asthma sufferer encounters problems in the house. Dust samples were not collected in some of the basements.

The samples were obtained by inserting a special dust collecting filter provided by the analyzing laboratory in the nozzle of a vacuum and

vacuuming the dust from the item under investigation. These samples were analyzed by the Dermatology, Allergy and Clinical Immunology Laboratory at Johns Hopkins University School of Medicine (5501 Hopkins Bayview Circle, Baltimore, Maryland 21224).

Air Leakage Test

An air leakage test was performed on each house to determine how air tight the houses were. The test was performed in accordance with CAN/GGSB-149.10-86 *Determination of the Overall Envelope Airtightness of Buildings by the Fan Depressurization Method.*

Air tightness testing is used by the R-2000 Program as one of the tools to determine compliance with the Program. To meet the R-2000 requirements for air tightness, the house must have a tested air leakage of less than 1.5 air changes per hour at 50 pascals (ACH@50Pa). The typical tract-built house in Canada today is around 3.5 ACH@50Pa and it is not unusual for a 25 year old house in Canada to have test values in the range of 5 to 10 ACH@50Pa or even greater.

5. HEALTH MONITORING

Information on the participants' health was obtained through interviews, through the participants completing detailed questionnaires before and after the renovation and by the participants monitoring their health over the period of the study.

The health monitoring part of the study consisted of symptom recording and peak flow measurements. On the advice of the medical advisers to the project, the participants were asked to measure PEFRs (Peak Expiratory Flow Rates) as an indicator of changes in their health over the study period. They were also asked to record any health-related symptoms or occurrences in the same notebook provided for recording their daily PEFRs.

At the outset of the study, the participants were invited to a meeting where a respiratory technician demonstrated how to measure peak flows and a peak flow meter was provided. The recorded reading was the best of three successive forced expirations.

Participants were asked to test their PEFRs every day, if possible, and to conduct a series of tests to compare their peak flows in the basement once a week for three weeks at the beginning of the study, during the beginning of the heating season and at the end of the study. The basements were identified as major problem areas with high mold counts in all of the houses. As well, most of the asthma sufferers had reported significant asthma problems when they visited the basement. The tests in the basement, therefore, were conducted to document any changes in the health of the asthma sufferer in the area where they had the most difficulty.

The daily test involved the participants measuring their peak flows when they awakened and just before they went to bed. At any point when they felt a change in their breathing, they were directed to take extra measurements. As well, they were asked to keep a record of events relating to activities, exposures, housing, lifestyle, stress, weather, and other factors that may have an impact on their breathing. In situations where the participant used medication, such as salbumatol (*Ventolin*) or atrovent, they were asked to measure their peak flow again after taking the medication.

Participant's peak flows in the basement were measured before, during and after entering the basement. The tests were conducted once a week for three weeks and were intended to document the impact of the basement environment on the participant's breathing. The participants were asked to withhold using their bronchodilator inhaler for six hours prior to conducting the testing and during the testing.

The testing took over two hours to complete and involved the following steps:

a) taking two peak flow measurements, 10 minutes apart, prior to going to the basement;

b) measuring their PEFR immediately after entering the basement;

c) taking peak flow measurements every ten minutes over the course of an hour while the participant was in the basement (if the participant could not stay in the basement that long, they were asked to take at least one measurement);

d) taking peak flow measurements immediately after exiting the basement and again every ten minutes over the course of an hour after having left the basement.

The participants were cautioned to put their safety above the study. At no point were they to place themselves in a situation where they could encounter health or safety problems.

When participants were away from home they were instructed to follow the same testing regimen — taking their PEFRs at morning and at night. If the participants were not going to be away, they were asked to take some peak flow readings after they had been outside for a while.

A mother and her son and four adults were invited as controls for the study. The mother and son dropped out. Two of the controls were the occupants of Houses 8 and 13.

6. RESULTS OF THE INDOOR AIR QUALITY TESTS BEFORE RENOVATION

A variety of parameters were analyzed to determine the presence of molds and other contaminants in each of the six houses. The results of all of the sampling carried out in each house is reported in Appendix A. This section summarizes the results of the testing carried out before the renovation work on the houses and documents the pre-renovation readings from each house which were higher than accepted levels or contained toxigenic or pathogenic molds.

Table 6.1
CO_2 Levels in Each House

House No.	1	2	3	4	5	6
Location	basement	master bedroom	master bedroom	master bedroom	master bedroom	master bedroom
Peak Reading (ppm)	750	1160	690	620	800	980
Average Reading (ppm)	510	650	465	450	570	700

Table 6.2
VOC Readings in Each House (Measurement taken in basement of each house)

Parameter	House No. 1	2	3	4	5	6
Total VOC (mg/m^3)	1.3	0.83	0.1	0.33	0.1	0.42
Dichlorodifluromethane		0.26				
Trichlorofluromethane		0.15				
Toluene		0.14		0.003		0.07
Ethylbenzene				0.010		
1-Chloro-1, 1-difluroethane	0.08					
Xylene	0.05	0.20		0.048		0.01
Xylene		0.07		0.013		0.004
Saturated Hydrocarbon	0.02					
Hydrocarbon	0.05			0.040		
alpha-Pinene	0.17	0.11				0.04
Saturated Hydrocarbon	0.18	0.11				0.007
Saturated Hydrocarbon	0.06					
Carene						0.009
3-Carene	0.08					
Trimethylbenzene		0.05		0.023		
Limonene	0.19	0.11		0.047		0.09
Saturated Hydrocarbon	0.17					
Tetramethylbenzene	0.13					
Hydrocarbon		0.14		0.011		

Table 6.3
Relative Humidity Readings in Each House

House No.	1	2	3	4	5	6
Date Reading Taken	11/06/97	16/06/97	19/06/97	26/06/97	08/07/97	18/07/97
Main Floor	67%	53%	60%	65%	58%	53%
Basement			54%	70%		59%

Table 6.4
Ergosterol Readings in Each House *(detection limit 0.1 ug m^3)*

House No.	1	2	3	4	5	6
Location	basement	basement	basement	laundry room	basement	basement
Result	no results	none detected	0.1 ug/m^3	0.1 ug/m^3	0.1 ug/m^3	<0.1 ug/m^3

Carbon Dioxide

In two of the houses the level of CO_2 in the master bedroom approached or exceeded levels above 1000 ppm. Table 6.1 presents the peak CO_2 readings detected in each house and the average reading detected over the two-day period.

VOCs

VOC readings were taken in the basement of each house. In houses 1, 2, 4 and 6 the laboratory identified the volatile organic compounds. In most cases these were associated with scented products and cleaning products. None of the houses had Total VOCs above the level of 2.0 mg/m^3. In houses 3 and 5 the Total VOC reading was only 0.1 mg/m^3 and the laboratory was unable to identify any specific VOCs. These very low VOC concentrations may possibly be due to a sampling or analysis defect.

Table 6.2 presents the VOC readings recorded for each house.

Relative Humidity

The relative humidity readings in the various houses were within the acceptable range for the warmer spring and summer months.

Ergosterol

The very low and undetectable readings obtained for these houses is not consistent with the moldy environments observed during the inspection of the houses. The results suggest difficulties with the sampling procedure or the analytical testing.

Molds, Fungi and Microbials

The mold testing results are summarized in Tables 6.5 to 6.12. Table 6.5 lists the molds identified in the houses in this study. Tables 6.6 to 6.13 compile the test results for each of the six selected houses before renovation and after renovation. The test results for the two control houses (Houses 8 and 13) are also included.

Table 6.5
Molds Identified in the Houses Under Study

Name	Characteristics	Found in Houses
Acremonium strictum	hydrophobic mold sometimes found on wet building materials	***5***
Alternaria alternata	phylloplane species common in outdoor air samples	1, 2, 3, 4, 5, 6
Aspergillus amstelodami	isolated from wide range of organic substrates, more common to tropical & subtropical regions	***4***
Aspergillus fumigatus	pathogenic & toxigenic	1, 4
Aspergillus niger	isolated from wide range of organic substrates it is a common degrader of organics	1, 4, 6
Aspergillus ochraceus	isolated from wide range of organic substrates	***4***, 5
Aspergillus restrictus	xerophile	***1, 3***
Aspergillus sydowii	isolated from wide range of organic substrates	3, ***5***, 6
Aspergillus ustus	isolated from wide range of organic substrates	1, 2, 4
Aspergillus versicolor	moderate xerophile — grows on wallboard & other organic material, often associated with condensation under vinyl wall coverings	1, 2, 3, 5
Aspergillus wentii	isolated from wide range of organic substrates	***3***, 4, 5
Aureobasidium pullulans		1, 3
Chaetomium globosum	hydrophilic soft-rot fungus causes destruction of cellulose layers in wood fibres	1, 3, 4, ***5***
Cladosporium cladosporioides	phylloplane species common in outdoor air samples	1, 2, 3, 4, 5, 6
Cladosporium herbarum	phylloplane species common in outdoor air samples	1, 2, 3, 4, 5, 6
Cladosporium sphaerospermum	grows on wet building materials — phylloplane species common to outdoor air samples	1, 2, 3, 4, 5, 6
Fusarium species		2, 4, 6
Gliocladium roseum	salt-tolerant species isolated from wet building materials including wallboard	1
Memnonielle species		4 (bulk)
Mucor hiemalis	isolated from many materials	2, 3, 4, 5, 6
Mucor species	isolated from wide range of organic substrates	1, 3, 4, 5
Paecilomyces variotii	moderate xerophile — grows on wallboard & other organic material, produces mycotoxins	1, ***4***, 6
Penicillium aurantiogriseum	toxigenic, can be pathogenic — grows on wet wallboard, is heat resistant, acid & salt-tolerant; volatiles are cytotoxic when inhaled	1, 2, 3, 4, 5
Penicillium bilaii	isolated from wide range of organic substrates	***2, 4***
Penicillium brevicompactum	moderate xerophile — grows on wallboard & other organic material, produces mycotoxins	1, 4, 6
Penicillium citrinum		5
Penicillium chrysogenum	common species found on food products as well as building materials, in indoor & outdoor air samples — non-sporulating isolates not found outdoors can be indicative of damp conditions indoors	1, 2, 3, 4, 5, 6
Penicillium commune	isolated from wide range of organic substrates	1, 2, 3, 4, 5
Penicillium corylophilum	isolated from wide range of organic substrates	1, 2, ***3***, 4, ***5***, 6
Penicillium crustosum	moderate xerophile — grows on wallboard & other organic material, is acid-tolerant & produces mycotoxins	***2***, 4, 5
Penicillium decumbens	isolated from wide range of organic substrates	1, 3, 5, 6
Penicillium fellutanum	isolated from wide range of organic substrates	1

Table 6.5
Molds Identified in the Houses Under Study (Continued)

Name	Characteristics	Found in Houses
Penicillium glabrum	isolated from wide range of organic substrates	***2***
Penicillium janthinellum	widespread, heat-resistant acid and salt-tolerant fungus — grows on decaying organic substrates; recently reported to cause invasive fungal disease	***2, 5***
Penicillium olsonii	isolated from wide range of organic substrates	1, 3, 4, 5
Penicillium oxalicum	isolated from wide range of organic substrates	1, 3, 4, 5
Penicillium purpurogenum	isolated from wide range of organic substrates	1, 2, 3, 4, 5
Penicillium restrictum	isolated from wide range of organic substrates	1, 6
Penicillium rugulosum	isolated from wide range of organic substrates	***3***, 4
Penicillium simplicissimum	isolated from wide range of organic substrates	1,2, ***4***, 5
Penicillium spinulosum	isolated from wide range of organic substrates	***1, 4***
Penicillium variabile	isolated from wide range of organic substrates	4
Penicillium verrucosum	isolated from wide range of organic substrates	5, 6
Penicillium viridicatum	moderate xerophile — grows on wallboard & other organic material, produces mycotoxins	1, 2, 3, 4, 5, 6
Penicillium species		1, 2, 3, 4, 5, 6
Phialophora mellinii	hydrophilic mold, usually found on very wet cellulose substrates	***4***
Rhizopus species		4, 5
Scopulariopsis brevicaulis	isolated from many materials	2, 3, ***4***
Stachybotrys chartarum	hydrophilic mold — isolated from materials containing cellulose including the paper side of wallboard; even non-viable spores are toxigenic and allergenic; high exposure can cause pulmonary hemosiderosis in infants and severe lung disease in adults	2, 4
Talaromyces flavus		1
Trichoderma harzianum	hydrophilic — grows on wood products	***1***, 5
Trichoderma viride	hydrophilic — grows on wood products	4
Ulocladium botrytis		3
Ulocladium chartarum	phylloplane species common in outdoor air samples, can grow on building materials	***1, 5***
Verticillium species	most species are plant pathogens	1, 4
Wallemia sebi	extreme xerophile, grows on organic matter	3, 4
and other microbials and bacteria, including:		
actinomycete	filamentous bacteria	***2***, 3, 4, 5
ascomycete (1)		4
bacteria — ivory		
non-sporulating isolate — beige/pink, green/orange/white, yellow/green edge and over 35 other variations of colour combinations		
unknown isolate		
yeasts — pink, black		
clamp connections		

Notes

xerophile — can grow under relatively drier conditions

hydrophilic — moisture loving

bolded, italic number indicates mold only found after renovation/clean up had been carried out

In Tables 6.6 to 6.13, each of the air samples was given either a Pass or Fail rating. The criteria used to determine the pass/fail rating was developed by Dr. David Miller for this study. A fail rating is assigned if one or more of the following criteria are met.

1. A high Miller ratio. A Miller ratio of 1 is good and 10 is bad. The Miller ratio[13], [*Penicillium+Aspergillus+Eurotium*] /Phylloplane, is the sum of the colony counts for all *Penicillium*, *Aspergillus* and *Eurotium* species divided by the colony counts for leaf or phylloplane molds.

2. Confirmed presence of *Stachybotrys chartarum*, *Aspergillus versicolor*, *Aspergillus fumigatus* and *Fusarium moniliforme*. A confirmed presence is more than 1 colony forming unit.

3. High mold counts. Mold counts in excess of 150 cfu/m^3 is indicative of a cause for concern[14].

The Miller ratio criterion was also applied to the dust samples. Currently, there are no clear benchmarks for dust samples. The mold counts per gram of dust sample were compared to values found in other studies. In Wallaceburg and the 52 home survey, 10e3/g was typical and 10e5 or 10e6/g was high.

The bulk, slide and swab samples have been labelled with either "There is growth" or "There is no growth". Growth refers to molds other than phylloplanes.

Table 6.6
House 1: Summary of Mold Testing Results Before Renovation

Air Samples (June 11, 1997)	
Outside air	84% phylloplane
Master bedroom	Fail (high mold counts)
Daughter's bedroom	Pass
Basement north side	Fail (high mold counts, Miller ratio > 5)
Basement south side	Fail (confirmed presence of *Aspergillus versicolor*, Miller ratio > 20)
Master bedroom (after fan test)	Not good (Miller ratio >1)
Basement (after fan test)	Fail (very high mold counts, Miller ratio > 2)
Bulk, Swab and Slide Samples (June 11, 1997)	
Basement wall above freezer	There was growth.
Humidifier on furnace	There was growth.
Humidifier drum	There was growth; confirmed presence of *Aspergillus versicolor*.
Dryer lint	There was no growth.
Brown stain behind dryer	There was growth.
Dehumidifier pan	There was growth.
Refrigerator drip pan	There was no growth.
Vacuum dust samples	200,000 cfu/g in 2%MEA, 610,000 in DG-18

Table 6.7
House 2: Summary of Mold Testing Results Before Renovation

Air Samples (June 16, 1997)	
Outside air	73% phylloplane
Dining room	Fail (confirmed presence of *Stachybotrys chartarum*)
Master bedroom	Pass
Basement office	Pass
Basement laundry	Fail (numerous *Aspergillus versicolor*, very high mold counts)
Basement (after fan test)	Fail (very high mold counts)
Main floor (after fan test)	Fail (very high mold counts)
Bulk, Swab and Slide Samples (June 11, 1997)	
Basement – carpet NW corner	There was growth.
Basement – shavings from stud, west wall	There was growth.
Basement – stud in fireplace room	There was growth.
Basement – yellow marks on ceiling tile	There was growth.
Basement – back of new plywood	There was growth.
Basement – floor drain	There was growth.
Basement – pressure-treated sleeper and bottom chord	There was growth; confirmed presence of *Aspergillus versicolor*, very high Miller ratio.
Vacuum dust sample	80,000 cfu/g in 2 MEA, 210,000 cfu/g in DG-18 (Miller ratio >3)

Table 6.8
House 3: Summary of Mold Testing Results Before Renovation

Air Samples (June 19, 1997)	
Outside air	Practically all phylloplane
Child's bedroom	Fail (very high mold counts)
Master bedroom	Fail (very high mold counts)
Basement – laundry	Fail (high mold counts)
Basement – family room	Fail (very high mold counts)
Main floor (after fan test)	Fail (high mold counts)
Basement (after fan test)	Fail (high mold counts)
Bulk and Swab Samples (June 19, 1997)	
Basement – south end – white powder on carpet	There was growth; confirmed presence of *Aspergillus versicolor.*
Basement – black fuzz on tile	There was no growth.
Basement – white fuzz on block wall	There was no growth.
Basement – cardboard on floor	There was growth.
Basement – black fuzz on tile under carpet	There was growth.
Basement – panelling over sump	There was growth.
Basement – ceiling tile	There was no growth.
Living room – caulking	There was growth.
Bathroom – duct/drop ceiling	There was growth.
Whirlpool bathtub	There was no growth.
Vacuum dust sample	140,000 cfu/g in 2 MEA; 670,000 cfu/g in DG-18

Table 6.9
House 4: Summary of Mold Testing Results Before Renovation

Air Samples (June 26, 1997)	
Outside	90% phylloplane
Main floor – all rooms	Fail (very high mold counts, very high Miller ratio)
Second floor – all rooms	Fail (very high mold counts, Miller ratio of 3)
Basement – north end	Fail (very high mold counts)
Basement – south end	Fail (very high mold counts)
Bedroom (after fan test)	Fail (high mold counts)
Basement (after fan test)	Fail (high mold counts)
Bulk and Swab Samples (June 26, 1997)	
2nd floor bathroom – under sink	There was growth; confirmed presence of *Memnionella* species.
2nd floor bathroom – dirt and dust in register	There was growth.
Dining room – main floor return	There was growth.
Basement at top of stairs	There was growth.
Basement – south wall	There was growth.
Basement – tile floor under toilet	There was growth.
Basement – wood joist	There was growth; confirmed presence of *Stachybotrys chartarum.*
Basement – rubble in northeast corner	There was no growth.
2nd floor bathroom – sink cabinet	There was growth.
Vacuum dust sample (whole house)	640,000 cfu/g in 2%MEA, 550,000 cfu/g in DG-18

Table 6.10
House 5: Summary of Mold Testing Results Before Renovation

Air Samples (July 8, 1997)	
Outside air	Over 90% phylloplane
3rd floor bedroom	Fail (very high mold counts)
Dining room	Fail (high mold counts)
Basement	Fail (very high mold counts, Miller ratio ~ 16, virtually all Penicillium)
2nd floor bedroom (after fan test)	Pass
Basement (after fan test)	Pass
Bulk and Swab Samples (July 8, 1997)	
Basement – grey fuzz at back of wood cabinet	There was growth.
Basement – cardboard box	There was growth.
Basement – brown fuzz on mortar	There was no growth.
Basement – white stuff on green wood by cold cellar	There was growth.
Basement – brown fuzz on cardboard	There was growth.
Basement – orange mold on hutch leg	There was growth.
Basement – white mold on wood crate	There was growth.
Daughter's room – dust between radiator	There was growth.
3rd floor – green spots on foam	There was growth.
3rd floor – cardboard box	There was growth.
3rd floor – dust and debris on tile	There was growth.
Basement – previously wet hardwood	There was growth.
Basement – surface of leather ski bag	There was growth; confirmed presence of *Aspergillus versicolor.*
Dining room – stained hardwood floor	There was growth.
Vacuum dust sample (main & 2nd floors)	1.5 million cfu/g in 2%MEA, 2.3 million cfu/g in DG-18 (Miller ratio of 1.1)

Table 6.11
House 6: Summary of Mold Testing Results Before Renovation

Air Samples (July 18, 1997)	
Outdoor air	87% phylloplanes
Second floor	Fail (high mold counts, Miller ratio of 5)
Basement	Fail (high mold counts, Miller ratio of 1.25)
Second floor?	Pass (Miller ratio of slightly <1)
Crawlspace	Fail (exceedingly high mold counts, all *Penicillium viridicatum*)
Basement – family room	Pass
Bulk and Swab Samples (July 18, 1997)	
Crawlspace – wood against interior wall	There was growth.
Crawlspace – ceiling tile backing	There was growth.
Crawlspace – fibre glass insulation	There was growth.
Basement – carpet in bathroom	There was growth.
Basement – cardboard on floor in furnace area	There was growth.
Basement – joist above DHW tank	There was growth.
Basement – wall beside furnace	There was growth.
2nd floor – white fuzz on ceiling	There was no growth.
Vacuum dust sample	210,000 cfu/g in 2%MEA (Miller ratio of 1.7), 180,000 cfu/g in DG-18 (Miller ratio of 1.1)

Table 6.12
House 8: Summary of Mold Testing Results
(Control House — Not Renovated)

Air Samples (September 10, 1997)	
Outdoor air	90% phyllopianes
Living room	Pass (all phyllopianes)
Rec room in basement	Pass
Laundry and shop	Pass
Bath and storage	Pass
Bulk Samples (September 10, 1997)	
Vacuum dust samples	690,000 cfu/g in 2% MEA (Miller ratio of 1.3), 560,000 cfu/g in DG-18

The inspection of House 8 showed it to be moldy. Refer to the appendix.

No remediation was undertaken.

Table 6.13
House 13: Summary of Mold Testing Results
(Control House — Not Renovated)

Air Samples (September 11, 1997)	
Outdoor air	None detected
Living room	Pass
Rec room in basement	Pass
Utility	Pass
Vacuum dust sample	340,000 cfu/g in 2%MEA, 56,000 cfu/g in DG-18 (Miller ratio of 6.4)

During the study period, no remediation was undertaken on House 13.

In November, 1998, the homeowners decided to gut and clean the basement. Watermarks were found on the foundation wall in the recreation room. Water was also found on top of the polyethylene lining the subfloor.

Air Leakage Tests

Table 6.14
Air Leakage Test Results for Each House

House No.	1	2	3	4	5	6
Equivalent Leakage Area	0.244 m^2	0.055 m^2	0.080 m^2	*	data not available	0.157 m^2
Air change per hour @ 50 Pa	10.3	4.0	5.3	*		6.9

* meaningful data could not be obtained for House 4 since it was semi-detached with an open header space between the two units

House Dust Mite Allergen

The abbreviations used in the following table are:
Der p I – *Dermatophagoides pteronyssinus*
Der f I – *Dermatophagoides farinae*

The risk factor ranges associated with the dust mite allergens[17] include:

- **Low** risk factor: <400 nanograms allergen per gram of house dust
- **Moderate** risk factor: 400 to 2,000 nanograms allergen per gram of house dust
- **High** risk factor for symptoms: 2,000 to 10,000 nanograms allergen per gram of house dust
- **High** risk factor for sensitization: >10,000 nanograms allergen per gram of house dust

Table 6.15
Dust Mite Sample Results

Sample No.	Location	Allergen	Result
H1-D1	bed and pillows	Der p I Der f I	<200 ng/gram dust (low) <200 ng/gram dust (low)
H1-D2	basement concrete floor	Der p I Der f I	<20 ng/gram dust (low) 800 ng/gram dust (mod)
H2-D1	master bedroom bed and pillows	Der p I Der f I	<30 ng/gram dust (low) **13,200 ng/gram dust (high)**
H2-D2	basement office floor carpet	Der p I Der f I	<20 ng/gram dust (low) 1,800 ng/gram dust (mod)
H3-D1	bed and pillows	Der p I Der f I	400 ng/gram dust (mod) 1,800 ng/gram dust (mod)
H3-D2	basement carpet	Der p I Der f I	1,700 ng/gram dust (mod) **5,800 ng/gram dust (high)**
H4-D1	bed and pillows	Der p I Der f I	<20 ng/gram dust (low) 600 ng/gram dust (mod)
H4-D2	second floor carpets and chairs	Der p I Der f I	80 ng/gram dust (low) **8,400 ng/gram dust (high)**
H5-D1	parent's and daughter's beds	Der p I Der f I	1,000 ng/gram dust (mod) 800 ng/gram dust (mod)
H5-D2	carpets – on 3rd floor and main floor	Der p I Der f I	200 ng/gram dust (low) 900 ng/gram dust (mod)
H6-D1	bed and pillows	Der p I Der f I	<20 ng/gram dust (low) 200 ng/gram dust (low)
H6-D2	basement carpet and couch	Der p I Der f I	<20 ng/gram dust (low) **38,800 ng/gram dust (high)**
H8-D1	living room couch and carpet	Der p I Der f I	<20 ng/gram dust (low) **81,700 ng/gram dust (high)**
H8-D2	basement couch and carpet	Der p I Der f I	<20 ng/gram dust (low) **76,000 ng/gram dust (high)**
H13-D1	living room couch	Der p I Der f I	<30 ng/gram dust (low) **15,100 ng/gram dust (high)**
H13-D2	basement carpet and couch	Der p I Der f I	100 ng/gram dust (low) **3,200 ng/gram dust (high)**

7. PREPARATION OF SPECIFICATION AND TENDERING PROCESS FOR REMEDIAL WORK

The preliminary remediation strategies identified previously were discussed with the homeowner and a specification for the work was created for each house. A bid meeting for contractors was held at the houses where it was deemed necessary, based on the type of work to be carried out. The quotes received from the contractors were reviewed with the homeowner, and advice was given regarding the contract award.

8. SITE VISITS AND CONTRACT SUPERVISION

Each house was periodically inspected during the progress of the renovation to ensure the clean up and renovation work met the specifications and the goals of the project. As with any construction project, as concealed areas were opened up, changes were suggested to the work to ensure the IAQ problems were adequately addressed. Discrepancies identified between the work carried out and the homeowner's renovation contract were drawn to the attention of the homeowner and the contractor. Buchan, Lawton, Parent Ltd and the homeowner carried out a final inspection of the remedial work in each house to ensure it met the terms of the construction contract. In a number of instances, the contractor was required to return and re-clean areas not adequately cleaned in the first place.

An overview of the proposed work for each house and the actual work carried out is included under each house profile in Appendix A.

In general, the work involved cleaning up areas of suspected and identified molds and fungi and, in some cases, improving the ventilation in each house through the installation of a heat recovery ventilator. In all cases, the work involved extensive cleaning and, for two houses, gutting and removal of partition walls and flooring in the basement of the house. Water drainage around the house was also identified as a problem and, as a minimum solution, it was suggested the grade be sloped away from the house. In one situation, the foundation was excavated and proper waterproofing, insulation and drainage was installed.

9. HIGHLIGHTS OF THE RESULTS OF THE FINAL IAQ MONITORING

In most cases, the final indoor air quality monitoring was carried out a minimum of one month after the completion of the final inspection and in some cases more than a few months. This ensured the houses had a chance to achieve a new equilibrium.

The following tables summarize the findings from the final series of IAQ tests and monitoring.

Relative Humidity

The relative humidity readings in the various houses fell within the acceptable range for the cooler winter months.

Molds, Fungi and Microbials

House 1: Summary of Remedial Work

The basement was cleaned with bleach and limed. The carpet in the master bedroom was replaced with hardwood. Vinyl tiles in the bathroom were replaced with ceramic tiles. An HRV was installed with central air conditioning. The recommended work on the foundation was not implemented.

Notes:

The basement smelled clean immediately after the clean up in the fall of 1997. However, during the inspection on March 20, 1998, the moldy odour and discolouration of the walls had returned. During the summer, the homeowners were advised to seal off the opening to the crawlspace. On a subsequent visit in September, 1998, after the crawlspace opening was sealed with plastic, the moldy odour in the basement was found to be reduced. Air samples at that time confirmed the house still had mold contamination. Visible mold growth on the basement walls, in spite of continuous dehumidification, indicated moisture from outside was entering the house through the foundation. The results from the air sampling showed the crawlspace was another source of contamination. Further remedial work was required. To prevent moisture entry, the foundation should be drained, waterproofed and insulated at the exterior. Additional work in the crawlspace would entail sealing the top course of the hollow block foundation, duct sealing and ensuring the earth floor was sealed.

Table 9.2
House 1 Summary of Mold Testing Results After Renovation

Air Samples (March 20, 1998)	
Outside air	Low mold counts
Master bedroom	Pass
Basement north end	Fail (very high mold counts, virtually all Penicillium)
Basement south and into crawlspace	Fail (very high Miller ratio)
Third floor	Fail (low counts but all Penicillium)
Bulk and Slide Samples (March 20, 1998)	
Basement stain above washing machine	There was growth; confirmed presence of *Aspergillus versicolor.*
Air Samples (September 11, 1998)	
Outdoor air	Very low counts
Basement north**	Fail (predominantly *Aspergillus versicolor*)
Basement south**	Pass (Miller ratio of 1)
Crawlspace at opening	Fail (very high Miller ratio)
Basement (forced air system running)	Fail (more than 1 cfu of *Aspergillus versicolor*)

Table 9.1
Relative Humidity Readings in Each House After Renovation

House No.	1	2	3	4	5	6
Date Reading Taken	20/03/98	13/03/98	24/02/98	03/03/98	24/02/98	
Main Floor	31%	53%	27%	42%	33%	N/A
Basement	35%	51%	30%	48%	38%	N/A

Table 9.3
House 2: Summary of Mold Testing Results During Renovation (Renovation not Complete)

Bulk and Swab Samples (December 11, 1997)	
Basement – black mold on cross bracing	There was growth.
Basement – backside of plywood	There was growth.
Basement – 2 x 4 between studs on west wall	There was growth.
Main floor – underside of cabinet	There was growth.
Air Samples (March 13, 1998)	
Outside air	Low counts
Living room, dining room, kitchen	Fail (confirmed presence of *A. versicolor*, very high Miller ratio)
Bedrooms	Fail (Miller ratio of 4)
Basement, old office area	Fail (very high Miller ratio)
Bulk Samples (March 13, 1998)	
Basement – pressure-treated wood by fireplace	There was growth; confirmed presence of *Stachybotrys chartarum*.
Drywall debris from basement	There was growth; confirmed presence of *Stachybotrys chartarum* and *Aspergillus versicolor*.
Joist in main floor bathroom at previous leak	Pass

Table 9.4
House 3: Summary of Mold Testing Results During and After Renovation

Bulk Samples Taken During Renovation Work	
Basement sub-floor	There was growth.
Joist, basement landing	There was growth.
Tile, under landing	There was growth.
Compressed paper in bathroom floor	There was growth.
Air Samples After Renovation Work Completed (February 24, 1998)	
Outside air	Very low counts
Office, formerly child's bedroom	Pass (very low counts, same as the outdoor sample)
Master bedroom	Pass (very low counts, Penicillium only[*])
Basement – laundry area	Pass (very low counts, Penicillium only[*])
Bulk Samples (February 24, 1998)	
Ceiling joist	There was no growth.
Air Samples After Further Renovation and Cleaning (March 25, 1998)	
Outdoor sample	Very low count, 60% phylloplane
Basement, beside and around chimney	Pass (very low count of phylloplanes)
New office and closet	Pass (no molds detected)

House 2: Summary of Remedial Work

The basement was partially gutted and cleaned with bleach. Framing for a partition wall and the brick finishing on one wall were retained. Furniture from the basement was moved upstairs without decontaminating them first.

Notes:
Contaminated furniture from the basement accounted for the contamination of the living room, dining room and kitchen. Two dangerous molds were found in this house. All remaining framing in the basement required removal and the basement thoroughly cleaned with bleach. Surfaces on the main floor also required cleaning. The existing HRV required upgrading to a better unit and the ducting improved. The long-term solution for this house required draining and insulating the foundation on the outside.

House 3: Summary of Remedial Work

The homeowners exceeded the minimum required renovation for participation in this project. The foundation was drained, waterproofed and insulated on the exterior. The basement was completely gutted and cleaned, and furnishings in the basement were discarded. An HRV was installed. The main floor was subjected to a thorough clean up — all surfaces were cleaned with bleach. All pieces of clothing were meticulously cleaned. The living room couch was removed from the house.

Notes:
In November, 1997 after the major work was completed, the house still had a slight smell of mold at the HRV exhaust. Further cleaning was recommended. Additional suggested work included sealing the top course of hollow blocks and replacing the basement windows (frames were rotten) in the basement. All renovation work was completed in December, 1997.

Inspections of the house on March 25, 1998 and in the summer of 1998 revealed neither visible molds nor moldy odour in the house. The basement was kept very clean. The homeowners maintained their HRV and operated a dehumidifier in the summer. The family was exceptionally meticulous in controlling moisture and other pollutants in the house.

House 4: Summary of Remedial Work

The basement was subjected to cleaning with bleach and lime. Penetrations were sealed with polyurethane foam. The ducts were cleaned. An HRV was not installed. With the exception of the removal of a carpet on the second floor, the upper floors essentially remained untouched.

Notes:
Although the house and the air in the house and the basement had markedly improved from before the renovation, this house still required much work. Further cleaning was suggested after the inspection on March 3, 1998. Decaying structural beams and windows in the basement required replacement. A thorough cleaning of upper parts of the house was needed. The furnishings and books were possible sources of pollution. Furthermore, until drainage and insulating of the foundation on the exterior was done, moisture entry to the house was going to be an ongoing problem. The use of a dehumidifier controlled the moisture to a degree, but may not be sufficient to prevent mold growth on the walls.

House 5: Summary of Remedial Work

The homeowners were prepared to do the minimum recommended work. The homeowners also installed a central air conditioning system including ductwork. The basement contained an extraordinary amount of stored furnishings. The majority was discarded. The basement was gutted and subjected to a bleach clean up followed by liming. An ERV (enthalpy recovery ventilator) was integrated into the air conditioning system.

Against the advice of the project co-ordinator, the homeowner decided to re-build the cold cellar. This area was insulated with glass fibre and

Table 9.5
House 4: Summary of Mold Testing Results During and After Renovation

Air Samples (March 3, 1998)	
Outside air	Low counts, 80% phylloplane
Living room	Fail (very high Miller ratio, all Penicillium)
Second floor	Fail (very high Miller ratio, all Penicillium)
Basement – south end	Fail (very high mold counts, Miller ratio of 16)
Basement – north end	Fail (very high mold counts, Miller ratio of 53)
Bulk Samples (March 3, 1998)	
Wood behind washer	There was growth.
2nd floor bathroom – joist	There was growth.
Air Samples After Further Cleaning (April 8, 1998)	
Outside air	Low counts, 50% phylloplane
Living room	Fail (very high mold counts, almost all Penicillium)
Basement – south end	Fail (Miller ratio > 2)
Basement – north end	Fail (very high mold counts, Miller ratio ~ 5)

Table 9.6
House 5: Summary of Mold Testing Results During and After Renovation

Air Samples (February 24, 1998)	
Outside air	Very low counts
Dining room	Pass (very low count, Miller ratio of 1)
Master bedroom	Fail (very low count but very high Miller ratio)
Third floor	Pass
Basement	Fail (Miller ratio of 1.25)
Swab Samples (February 24, 1998)	
Surface of antique desk	There was growth; confirmed presence of *Aspergillus versicolor.*
Wood near radiator in dining room	There was growth.
Air Samples (September 11, 1998)	
Outside air	100% Phylloplane
Basement – west side	Fail (low mold counts, Miller ratio of 2)
Basement – east side	Fail (high mold counts, numerous colonies of *Aspergillus versicolor*).
Cold cellar	Fail (high counts, numerous colonies of *Aspergillus versicolor).*

finished with gypsum wallboard. The contractor installed a small fan on the window opening in this room.

Notes:
In the summer of 1998, inspection of the house showed marked improvement of the air on the main floor compared to before the renovation. However, localized areas in the basement showed the presence of musty odours. The west side of the basement, where the ERV was located, smelled better than the east part of the basement, adjacent to the cold cellar. The cold cellar smelled exceedingly musty. Since winter, the homeowner had boarded up the window, and consequently, the small exhaust fan had not been operating. The homeowners were advised to operate the exhaust fan and clean the cold cellar surfaces with bleach. On September 11, 1998, when re-testing was done, the fan had been operating for two weeks.

Unfortunately, mold had taken a foothold in the cold cellar area and in the adjoining room in the basement. To eliminate the mold, this cold cellar requires gutting and the foundation walls cleaned with bleach. As was advised in the beginning, the basement walls cannot be covered. The cold cellar, isolated and closed up from fall, 1997 to the end of August, 1998, had no mechanism for moisture removal.

Long-term prevention of moisture entry through the foundation walls requires drainage, water-proofing and insulation of the foundation walls on the outside and vigilant control of moisture inside the house.

House 6: Summary of Remedial Work

No remedial work was undertaken on House 6.

10. HEALTH MONITORING BEFORE AND AFTER RENOVATION: SELF-REPORTED SYMPTOMS AND OBSERVATIONS

House 1

Health History (before renovation)

The 48 year old female homeowner had asthma. She had lived in the house with her husband and two teenage children for seven years. She had been diagnosed with asthma six years earlier.

She began to experience symptoms eight months after moving into their current house and she was diagnosed with asthma a few months later. Her asthma worsened in the last two years before the study.

Her symptoms were worse from the beginning of June to October and especially at times when the humidity was high. Very cold weather and hot, humid weather triggered her asthma. She suffered from shortness of breath at nights before going to sleep. In the mornings, she coughed a lot (for about an hour) and had to clear her throat. Her most difficult times were when she was so short of breath that she could not talk. When she was having trouble breathing, she was more likely to feel her throat constricted than to feel wheezy. Her skin would get itchy, and she would often get hives in the mornings.

Allergy tests showed allergies to dusts and molds, dogs and cats. She also reported being affected by aerosols, chemical smells, perfumes, construction activity, pesticides, new materials and cigarette smoke.

The symptoms and asthma attacks were experienced three to four times a week. She was using a steroid puffer (*Pulmicort*) twice a day and a sodium chromoglycate inhaler (*Intal*) four times a day.

She reported feeling better outside than inside her house, except when the outdoor relative humidity was high or when there was a pollution advisory warning. As a consultant, she often went to her clients' homes where she found she felt better than in her own home.

Her 18 year old daughter developed allergic symptoms and exercise-induced asthma subsequent to moving into the house. Her 17 year old son developed a tendency toward winter-long colds subsequent to moving in. Her husband developed chest congestion and had pneumonia twice since the family moved to the house.

She noticed a musty smell upon entering the house. She found the basement damp and did not like staying there.

Summary of Renovation Work

Stored materials were removed from the basement. The basement floor, walls and ceiling were cleaned with bleach and lime washed. The carpet in the bedroom was removed and new hardwood flooring was installed. Ceramic tiles were replaced on the old bathroom floors. The floor of the third floor attic was painted and pine walls were sealed. Air conditioning for the whole house was installed. An HRV was installed, with the fresh air supplied to the return air and the exhaust air grilles were located in the basement, kitchen and two second floor bathrooms.

The family had initially intended to drain and insulate the foundation wall on the outside of the house. However, the estimate for all the work, including the improvements the family desired outside of the recommendations for indoor air quality purposes, was a lot higher than the family was willing to spend. Consequently, the planned work on the outside of the house was dropped.

At the completion of the renovation work, John VandeKleut of Buchan, Lawton, Parent Ltd inspected the house and, at that time, informed the homeowners that sealing the entrance to the crawlspace with polyethylene would be advisable to keep the air from the crawlspace from circulating into the house.

Health Observations after Renovation

The family was away from the house during the renovation. Upon their return, the female homeowner did not detect any change in her health and well-being. She noticed new smells from the renovation, and she was not able to use the third floor office because of the stain applied on the pine walls. The paint smells and other chemical smells caused severe headaches and she was not able to use certain parts of the home.

The frequency of the asthma attacks was about the same as before. The types and dosages of the medication had not changed. There was some improvement at night as a result of the reduction in humidity in the bedroom (from the air conditioning and the installation of an HRV). She also reported getting more colds in the winter after the renovation than before. She also felt the same in her basement after the renovation as before. She was able to stay in her basement or the same length of time as before. She was somewhat disappointed in the lack of improvement in the health of anyone in the family from the basement work.

Notes

On July 24, 1998, Virginia Salares visited the house and stayed in the basement for about an hour. She confirmed the basement still smelled moldy, and within half an hour, her throat was sore. She advised the homeowner to carefully seal off the openings to the crawlspace with polyethylene, as had been recommended earlier but had not been done. The crawlspace, under the new addition, was earth covered with polyethylene and weighted with sand. The polyethylene under the sand may not have been installed properly when the addition was built and dust and molds from the crawlspace were being pulled into the rest of the house by the forced air distribution system.

A re-testing of the air was done after the crawlspace openings were sealed. On September 11, 1998, Virginia Salares revisited the house to test the air in the basement. At that time, the basement smell had markedly improved indicating the crawlspace was the source of the molds. The air sample showed the presence of *Aspergillus versicolor* — consistent with the swab samples taken from the basement walls in March 1998.

At the end of the study, the mold problem in this house had not been adequately addressed. The moisture infiltration through the basement walls must be halted and additional work in the crawlspace is needed.

House 2

Health History (before renovation)

The 44 year old male homeowner had asthma and had lived in the house for 10 years. During the course of the study, he was the lone occupant of the house.

He was diagnosed with asthma when he was 7 years old. The asthma became more noticeable when he moved into his house and worsened a few years before the study. The homeowner felt the aggravation of his symptoms was related to flooding due to a broken pipe in his basement in 1994. He described his asthma as severe and it affected how he functioned on a daily basis. He experienced wheezing and breathing problems, mostly at nights. He also got headaches and stuffy nose. His symptoms were worse in the fall, when the heating system was turned on, and in winter. In the twelve months before the study, the asthma attacks were occurring every day.

Allergy tests showed positive for dusts. He reported sensitivity to strong perfumes, candle burning fumes, wine and beer. He used *Ventolin* and *Beclofort* inhalers everyday.

He reported feeling better outside than inside his house. The bedroom and the basement appeared to make his asthma worse. He did not like the basement, and only went down when absolutely necessary.

Summary of Renovation Work

The homeowner initially appeared to be committed to undertaking the renovation work. However, after he was given the list of required and recommended remedial work, he spent the next six months trying to obtain compensation

from the insurance company that had previously cleaned up his house after an earlier flood. When this approach failed, he sought compensation from the contractor who performed the previous clean up work.

As time ran out for participation in the study, the homeowner tackled the clean up himself. He was advised to engage a contractor to avoid health problems. He not only gutted his basement by himself, he admitted to not wearing respiratory equipment while carrying out the work. He informed the consultant that, at times he could not go on with the work in the basement, because he was too ill. He did not complete the remedial work required for the study. He refused to remove all of the structural wood and the brick facing on a wall in the basement.

Health Observations after Renovation

Since the renovations were not completed within the time frame of the study, it was not possible to obtain health observations after the renovation work.

By the time the deadline for testing under this study had been reached, the basement was still in a state of partial clean up. Test results from a piece of a pressure-treated wood forming a bottom sill plate in the basement indicated it was contaminated, and the air in the basement continued to be contaminated with the toxic molds. The air in the dining room was more severely contaminated than before the clean up — a result of the introduction of contaminated furniture from the basement to the upstairs.

These test results indicated a more complete gutting of the basement and more thorough cleaning was required to achieve the clean up originally recommended at the outset of the study. Another set of tests would be needed to assess the effectiveness of the cleaning.

In addition to the decontamination and clean up, the recommended major work for House 2 involved excavation of the exterior foundation for drainage and insulating purposes. This work was not carried out.

In the spring of 1998, the homeowner received some compensation from the contractor through a small claims court settlement. Because the time allotted for the study had run out, the homeowner was left on his own. His delay in completing the work cost him the opportunity to have his house and his health monitored.

House 3

Health History (before renovation)

The four year old daughter, who was born in this house, had asthma. The family had lived in this house for six years. The mother did not have asthma, but had been recently diagnosed with allergies and sensitivities.

Mother

The mother started experiencing symptoms a couple of years earlier. The symptoms included waking up tired, dizziness during the day, problems concentrating, feeling anxious, diarrhea, chest tightness and swelling in the mouth. These symptoms were getting worse, to the point where she feared she would not be able to continue working. She had hay fever symptoms during the weed pollen season. She was sensitive to egg, wheat, dairy, coffee, chocolate, monosodium glutamate and sulfites. Her symptoms were worse in hot and humid weather and when exposed to polluted air, cigarette smoke, scents or perfumes, dust, feathers, vehicle exhaust, moldy places. Chemicals released by furniture and building materials aggravated her symptoms.

The symptoms were continuous, indoors at home or at work, outside the home, in shopping centers and even certain places outdoors. According to her, "It was bad everywhere." Since the family had not been away from their home she was not able to determine if the symptoms would disappear in another indoor environment.

She noted the basement smelled moldy. As well, whenever the furnace started, she detected a pungent smell identified as ozone from the electronic air cleaner.

Daughter

The daughter first exhibited symptoms of asthma at 3 months and was diagnosed with asthma a few months later. She coughed and wheezed, was

breathless and had chest tightness during an asthma attack. Her symptoms were worse in the fall and winter. The asthma attacks occurred about once a month, usually accompanying a cold or a flu. In May, she had attacks without the usual triggers.

Allergy tests for the daughter were positive for animals (cats, dogs, horses, rabbits, etc.) and foods (dairy, eggs, nuts, peanuts, seeds).

Under normal circumstances, without the triggers, the asthma was controlled by medication. She took two puffs of *Beclovent* twice a day every day. During an asthma attack, the frequency was increased to four times a day. She was also given two puffs of *Ventolin* every four hours, as needed, during an asthma attack.

Summary of Renovation Work

The family proved to be ideal participants for the study. The interest and commitment of the female homeowner was phenomenal. Through her understanding of the health implications of the mold on herself and their daughter, she persuaded her husband, who was reluctant at first, to undertake all the remediation required to eliminate the molds. Not only was the minimum required work carried out, the exterior work to drain and insulate the basement foundation was completed. The total cost of the renovations ($36,000) was considerable. Since the homeowners loved the location and the community, they decided to rectify the house rather than move.

The couple painstakingly cleaned the whole house. All materials stored in the basement were either washed or discarded and even the main floor was subjected to the bleach clean up. All belongings were cleaned one piece at a time. The living room sofa was discarded. The walls, ceilings, floor, furniture and every surface on the main floor were cleaned with bleach. The furnace was cleaned, ducts were replaced with new ones and an HRV was installed. The fresh air supply was connected to the return air duct and exhaust air was removed from the basement, kitchen and bathroom.

At two post-renovation assessments in October, 1997, John VandeKleut and Virginia Salares found the house was less moldy than during previous visits but there was still a smell of mold in the basement. The exhaust air from the HRV clearly had a smell of mold. Further inspection showed areas where the cleaning contractor had missed. Furthermore, the window frames in the basement had rotted and the glass fibre insulation around the frames was wet and moldy. Sealing was needed at the top of the hollow concrete block foundation to prevent air from within the block cores moving into the indoor space. Additional sealing was required at the header joists where glass fibre insulation covered with polyethylene was leaking air. These problem areas were corrected and the windows were replaced. The renovation was completed by December, 1997.

The house smelled fresh and clean when it was revisited in the spring of 1998 — markedly different from the incredibly moldy house before. The mold tests in February showed very low counts of molds. The tests taken in March 1998 showed there was no longer a concern with mold.

Health Observations after Renovation

During the major part of the renovation, the family rented an apartment for three weeks. Their daughter was kept out of the house while the parents cleaned the main floor themselves, using masks when cleaning with bleach.

Mother

The renovation was very stressful for her and she worked long days carrying out the cleaning up. She was tired and exhausted, but relieved when they returned to the house. She did not feel any change in her well-being immediately — she could smell the paint (on the concrete floor), the bleach and the acoustical sealant used on the header joists in the basement. The odours irritated her throat and caused swelling under her tongue and, at the same time, she continued to experience insomnia, tiredness and dizziness. When the new smells had dissipated, she could still smell some mold (consistent with the findings of Virginia Salares and John VandeKleut at the first post-renovation visit).

In late November, 1997, she had her first asthma attack after spending a day in a barn and riding a horse. She later found out she was allergic to

horses. This incident made her very sensitive for a couple of weeks.

Between October and early December, 1997, her allergy symptoms were the same as before. From the end of December to March, her symptoms became milder and she reported she was getting better. The coughing, chest tightness, sore throat and mucus in her throat gradually became less. Her medication was reduced by half. She reported fewer colds in the winter of 1997/98 than in previous winters.

By the beginning of March she noticed she had more energy than before. Though she was not completely better, she was more active in the evenings and did not collapse right after supper as she used to. She also noted she was more comfortable, rested and relaxed in her house after the renovation than before. She found she noticed new odours in her house more easily, but was less bothered by them. She was also able to tolerate more foods than before. She reported less stress, less insomnia, the "brain shiver" was almost gone, less weakness, more energy, less diarrhea, almost no swelling under her tongue, and the dizziness was less severe.

She felt much better in the basement than before. Previously, the smell was so bad she could not spend time in the basement. The improvement was great. She was able to spend more time in the basement, although there was less reason to be there.

She observed a very noticeable improvement in her health following the renovation. There was a difference in her ability to work not only at home but also at work. She typically worked at home one or two days a week and, after the renovation, she was less tired and weak and had less diarrhea and had more energy and concentration. At the office, she had more energy and was less bothered by environmental pollutants and lack of ventilation.

Daughter

The daughter had a bout with a cold that led to shortness of breath and coughing after moving to the apartment. She had no asthma symptoms when the family returned to their house on October 13. At that time of the year in the past (in their own home), she usually had severe problems. After they moved back to the house, she had intermittent coughing. A few days later, she was coughing a lot more and was prescribed antibiotics by her doctor. The coughing stopped in a week's time. Between the end of October and the beginning of March, she did not visit the doctor. In past years, visits to the doctor averaged once a month.

In the beginning of December, her nose started running and her throat became irritated, but she cleared quickly. She also had a small cold, or an allergic reaction, consisting of runny nose, mucus in throat and coughing that went away quickly. After the renovation, the asthma attacks were less frequent than before. The symptoms during an asthma attack were the same and the medication was not changed. However, overall, there was less coughing, breathlessness, sore throats and mucus in her throat. Her skin was reported to be more dry or itchy.

Her parents were pleasantly surprised with her health. In the 1997/98 winter, she did not catch as many colds or the flu as in previous winters. She had no asthma symptoms in November, January and February. In the past, her asthma was triggered by a respiratory infection. Her parents believed her health was been greatly improved.

House 4

Health History (before renovation)

The female homeowner had asthma. She and her husband had lived in the house barely a year. She was diagnosed with asthma in June of 1995. Her condition became severe in May, 1996, approximately two months after moving into the house.

She had sinus problems every spring for three years before moving into the house under investigation. After moving into the house, her symptoms become dramatically worse and her sinus problems occurred constantly. During her first spring in the house, a really bad cough would not go away.

Her asthma attacks occurred on average between once a week and once every two weeks, but

sometimes far more often. During an asthma attack, she experienced coughing and chest tightness and sometimes wheezing and breathlessness. Between asthma attacks, she experienced coughing and breathlessness continuously. Her symptoms were worse from the time the furnace was turned on in the fall through winter and spring until the furnace was turned off.

Allergy tests all showed negative. She regarded these results as suspicious, since she reacted to cats, wool, perfumes and cigarette smoke. In addition, her breathing was worse when exposed to respiratory infections, molds or mildew, cold humid weather, hot humid weather, air pollution, dust and vehicle exhaust.

She was taking 2 puffs of *Flovent* twice a day, 2 puffs of *Flunase* and *Maxair*. She did not notice a big difference between how she felt outside and inside. She also appeared to have asthma attacks at home and at work (a church office). She had a hard time breathing while on a holiday for a week at a friend's cottage in England where it was damp and moldy.

She reported a musty smell in the basement and breathing problems in that part of the house. Her own physician, who was a friend of the family and who had known her for many years, suggested she participate in this study. He correlated the onset of the asthma with the move to the house.

Summary of Renovation Work

Most of the steps (seven of the eight) falling under the minimum required work suggested for the house were carried out. The bulk of the items stored in the basement were discarded. The bathroom (walls and fixtures) in the basement was removed. The walls and ceiling were bleached, then lime washed. Penetrations were foamed, and ducts were airsealed and cleaned. The carpet on the stairs to the second floor was removed. An HRV was not installed.

The second series of indoor air quality tests in the house were carried out at the completion of the renovation work in March, 1998. This was several months after the bleach clean up and lime washing had been carried out in the basement. The testing showed the presence of molds and high numbers of toxic mold counts in the basement.

One of the outcomes of this study was to identify the need to carry out IAQ tests immediately after the bleaching and lime washing, rather than wait until the other areas of the house were cleaned. Because of the delay between cleaning and testing, it was not possible to differentiate whether the molds had re-grown or whether they were not all eliminated during the clean-up. It was also possible the contamination was from materials stored in the basement.

The homeowners were instructed to further clean the basement and the bathroom on the second floor where a leak had occurred. Subsequent testing after the additional clean up revealed high total mold counts in the living room, with a few counts of a toxic species, lower counts at the south side of the basement and high total counts at the north end of the basement with significant counts of *Penicillium aurantiogriseum*.

Health Observations after Renovation

The homeowners left their house in early August, 1997 during the renovation. The female occupant felt better away from the house. Upon her return, she found the house smelled better than before. To her, it was clean smelling.

Between the fall of 1997 and June, 1998, she did not have any asthma attacks. The first asthma attack happened at the end of June on a trip to Toronto. Smog warnings were in effect at that time.

In her own words, she was "strikingly better than before" and she was very pleased with her health. Whereas she used to take 4 puffs of 250 microgram *Flovent* a day before the renovation, she was taking 2 puffs of 125 microgram *Flovent* a day afterwards. She had fewer colds in the 1997/98 winter than before. She was also breathing easier than before. The coughing, breathlessness, lightheadedness, dizziness, chest tightness, mucus in throat, nosebleeds, itchy nose and itchy skin had all improved.

She felt her energy level had not changed. However, she was more comfortable and felt more

rested in her house. She was able to work more inside her house. She felt much better in her basement. Prior to the renovation, she was not able to go into the basement. Afterwards she was able go downstairs without any symptoms and, consequently, was able to spend more time there.

According to her physician, her asthma had dramatically improved. Her asthma was much better and more manageable. The renovation had been dramatically helpful. She had provided him with peak flow readings continuously during the study. The symptoms were not only less frequent, they were also less severe. The need for medication (anti-inflammatory steroids) was much less than before the renovation. At the end of the study, her physician observed her problem was sinusitis, a much less life-threatening condition than asthma.

Notes

On July 28, 1998, Virginia Salares visited the house and found the basement relatively dry and pleasant. It did not smell of mold. A dehumidifier was running. The difference between this visit and a previous visit before the renovation was remarkable. Some stored materials were identified as possible sources of the molds. The homeowners were advised to remove these materials from the house.

The homeowners were also advised to block and seal an unused duct in the outside wall of the basement. The duct previously provided combustion air to the furnace and had not been removed when the new high efficiency furnace was installed. The duct was possibly bringing moist air into the basement during the warm months from a location close to the damp ground at the back of the house. Since the new furnace had a dedicated supply and exhaust air, this passive air supply was no longer needed.

High mold counts in the living room were thought to be related to the extensive collection of books and old upholstered furniture. Decontaminating the living room would be a challenge for homeowners who both loved books and had a large collection. Many of the books would be nearly impossible to decontaminate. Some of the upholstered furniture could conceivably have been the source of the mold spores.

On August 18, 1998, the female homeowner reported she was off her asthma medication. The old living room sofa had been replaced.

House 5

Health History (before renovation)

The female homeowner had asthma. She had lived in the house with her husband for six years. They had two children. The eldest child, a four year old girl, also had asthma and had had pneumonia every winter. The younger child had respiratory problems. The husband suffered from post-nasal drip. Participation in the study was due to her motivation to improve her asthma.

Mother

She was 39 years old and was diagnosed with asthma in 1989. After she moved to the house, she had had minor symptoms the first summer and they became progressively worse the following summers. Her symptoms became more serious during her pregnancy with her second child in the winter of 1996. That fall, she had sinusitis, followed by bronchitis, and she was sick over the entire holidays with bronchitis.

When she had an asthma attack, she experienced coughing, wheezing, breathlessness and chest tightness. At the beginning of the heating season in the fall, her asthma became worse. Her symptoms were worse between November to January and from May to August. Her asthma was better when the weather was dry in the summer months. Triggers were respiratory infections, stress, molds or mildew, hot humid weather, cigarette smoke, scents or perfumes and dust.

She had asthma attacks at least twice a week in the 12 months before the renovation. Between asthma attacks, she suffered symptoms of breathlessness and nasal stuffiness continuously. Allergy tests were positive for grass, dust, dust mites and molds.

She used *Ventolin* and *Becloforte* puffers twice a day, up to four times as needed. Her symptoms were worse at home. During an asthma attack, even her bedroom was a problem. She also

became sick in bars and restaurants. She always felt better outside than inside. In the summer, she got away from her house by spending time at their country home in Quebec. Although the cottage did not have the best indoor air, for her it was better than her home. The air was dry inside the house. Her throat felt sore and irritated, and she had nosebleeds. The kitchen, the bathroom and the basement were the worst locations in her house. She went to the basement only occasionally to do the laundry. She did not like the basement which she finds damp. Dusting, washing clothes and cooking made her breathing worse.

Children

The eldest daughter (almost four years old at the beginning of the study) developed asthma while she was still nursing. She had had pneumonia every winter and had been sick from January to March each year since she was born. She was put on *Flovent* during the first year, but it did not make a difference at all. The younger son (four months old at the beginning of the study) also frequently had a blocked nose. He had been to the hospital many times.

Summary of Renovation Work

Many of the recommendations listed under the category Minimum Required Work were followed when the renovations were carried out. The following items were not done: the damaged hardwood floor was not replaced, it was cleaned with bleach; the third floor was not cleared or cleaned; the grade against the building was unchanged; and the gas stove was unchanged.

The cold cellar in the basement was considered a potential growth site for molds. Against the advice of the project team, the cold cellar was re-built instead of leaving it bare. The room was re-insulated, covered with polyethylene and drywalled. An exhaust fan and supply duct were installed in the window opening of the cold cellar and left operational at the completion of the renovation.

Several items were returned to the basement after the clean up. These pieces of furniture had not been de-contaminated. Subsequent swab tests identified certain pieces of furniture as the source of molds.

Whenever the gas stove was used, the range hood was also turned on to minimize exposure to combustion by-products. Central air conditioning replaced the window units in the dining room and the homeowner's bedroom. The ERV (enthalpy recovery ventilator) was installed with dedicated exhaust grilles in the basement, kitchen and both bathrooms. The supply air ducts were run to the living room, dining room and bedrooms.

At the time when the basement was bleached and lime washed, there was no detectable odour of mold and the clean up appeared to have been effective. The mold testing in February, 1998 showed higher mold counts in the basement with some toxic species. Two of the species were traced to an antique desk that had not been decontaminated before it was returned to the basement. A swab sample of the mold-damaged floor in the dining room also contained one of the toxigenic molds. Subsequent to the testing, the antique desk was discarded. The damaged portion of the floor in the dining room was cleaned with bleach again, and the homeowners intended to have it replaced.

Health Observations after Renovation

Mother

The family was away when the major part of the renovation was underway. When the family returned, there was still a lot of dust in the air, and there was more work to be completed. The female homeowner felt sick and this lasted approximately one week. There were new smells from the renovation and she could smell dust in the air and this caused her nose to swell.

In the first few weeks after their return, she experienced more frequent asthma attacks — about twice a week. Within two months, the attacks were very few — one every two or three months. The frequency of the asthma attacks not only decreased, the symptoms became milder. She was also taking less medication.

She had fewer colds in the 1997/98 winter and she was able to breathe more easily than before. The colds she used to get almost always developed into bronchitis, lasting up to 3 months. She used to take lots of medications. After the renovation, the colds went away without medication. The

symptoms of coughing, wheezing, breathlessness, lightheadedness, dizziness and chest tightness had improved, while the sore throat, mucus in throat, itchy nose and dry or itchy skin were the same. The 1997/98 winter was the first winter she was comfortable in the house.

She had more energy than before and she was more comfortable, relaxed and rested inside the house. She noticed fewer odours in the house and she was less bothered by odours since the renovation. She was able to tolerate more foods than before. She felt much better in the basement than before. In the past, the basement made her feel nauseated. After the renovation, she felt nothing, and she was able to spend more time in the basement. In previous years, she always preferred their country home. Even though the air was not the best quality, she could breathe better in the country. Since the renovation, she actually preferred to stay in their city home, and her asthma was better. Overall, there was a marked improvement in her health.

Children

The daughter had no asthma or pneumonia in the 1997/98 winter, compared to frequent asthma and yearly bouts of pneumonia in the previous years since she was born. When she used to have coughs, they would develop into pneumonia. In the 1997/98 winter when she had coughs they did not develop into anything else. She missed only two days of school in total, compared to a month the previous year. Her pediatrician put her on *Flovent* this year. In her first year, the same medication had made no difference for her.

The son developed croup in November, 1997. He has been to the hospital a total of 25 times since he was born. His doctor put him on *Flovent* and this appeared to keep his symptoms under control.

Notes

On July 15, 1998, Virginia Salares visited the house to assess the air quality in the home and to interview the homeowner.

On the main floor, the air quality had improved compared with the air quality before the renovation. The air smelled fresher. The air quality in the main part of the basement had also improved. The ERV extracted stale air from this area and moisture control was augmented by operating a dehumidifier. A smell of mold, however, was clearly noticeable from the cold cellar.

The odour of mold from the cold cellar was believed to be mold taking a new foothold. The cold cellar had a door separating it from the rest of the basement. The enclosed space did not receive the benefit of dehumidification or venting through the central ventilation system. Its air was damp from moisture entering through the foundation and the floor — the same conditions as before the renovation. As well, the gypsum wallboard was unsuitable for the area since it would support the growth of molds in humid conditions.

A later visit to the site in September 1998 revealed continued improvements in the air quality of the home. The odour of mold in the area of the cold cellar was significantly reduced. Apparently the exhaust fan installed in the exterior wall of the room had been closed off with insulation for the winter months and the insulation had not been removed in the spring. When the exhaust fan was reinstated and operating, the moisture levels were controlled.

Air samples in the cold cellar and the basement area adjacent to the cold cellar showed significant growth of *Aspergillus versicolor*. The other area of the basement containing the ERV and dehumidifier showed low mold counts and no toxigenic species.

Cleaning in and outside the cold cellar was indicated. Re-testing would be required after the cleaning. If the molds persisted, the cold cellar would have to be gutted.

Keeping the mold from re-growing in the house will require vigilance. Until the foundation is drained and insulated on the outside, dehumidification has to continue. The homeowners could also monitor ambient air humidity and turn the ERV off when the relative humidity outdoors was high.

House 6

Health History (before renovation)

The fifteen year old female daughter had asthma. She had lived with her family in the house since she was born. According to her mother, she

suffered from a severe case of asthma, had an anaphylactic allergy to milk proteins and had diabetes. She was constantly sick and had been in the intensive care unit of the hospital a few times.

The known triggers of her asthma were respiratory infections and mold in the fall and spring. She had undertaken allergy tests and tested positive for molds. She was due for re-testing. She took *Decadron* (a steroid), *Flovent*, *Ventolin* and insulin. She could not go on *Prednisone*.

The last asthma attack was triggered by a sleepover in the basement. When the carpet was installed in the basement ten years earlier, she had severe headaches. At the outset of the study, she would get wheezy when she was down there.

Summary of Renovation Work

This house was not renovated.

The homeowners had initially appeared to be very interested in participating in this study. Their house had an obvious mold problem, a localized source of molds (i.e. the earth-floor crawl space), and a very sick daughter. The basement had been identified as a trigger of their daughter's asthma attacks and wheeziness. This house was included in the study based on the interest shown by the homeowners, the severity of the health problem and the presence of a housing/health connection. Because the house was located in an established area of higher priced homes, there was an expectation that the renovation cost would not be a financial burden. This was further inferred from recent renovations, including a new kitchen, master bedroom with its own remote control operated gas fireplace and TV, and a Jacuzzi in the ensuite bathroom.

The homeowners expressed a willingness to spend around $5,000. The mold test results showed the crawl space to be highly contaminated with *Penicillium viridicatum*, a toxigenic mold. The same mold was detected in the basement air. This mold was not seen in the upper floors at the time of the testing (summer). However, during the heating season when the forced air system and stack effect were both operating, the basement air would be distributed throughout the house, and any mold spores would likely contaminate the whole house. One type of dust mite allergen from the carpet and sofa in the basement was found to be very high.

The recommendations for remediation given to the homeowner took into account the severe contamination with the toxic mold. If the crawlspace was less contaminated, covering the crawl space with polyethylene may have sufficed. However, in this case, because of the very high mold counts of *Penicillium viridicatum*, it was recommended that the walls, joists and subfloor of the crawlspace be cleaned with bleach. The very low height of the crawlspace and lack of ventilation presented challenges and health risks to contractors who would do the clean up. As a result, the contractors' estimates were higher than the original estimates.

Negotiations were carried out with the homeowners to pare down the work in order to make it more affordable and yet remedy the mold contamination. The homeowner was partial to depressurizing the crawlspace without cleaning up the mold, as suggested by a contractor whom he found and who was also trying to convince him to depressurize and finish the basement walls. These suggestions did not address the problem at hand in a fully satisfactory and effective manner.

The homeowner decided not to go ahead with the recommended renovations for a variety of reasons, including: the expense would not be viewed as an improvement to the home in the same way as a kitchen improvement and, therefore, would not add value to the house; they could not afford the renovation; no one in the family had died since living in the house; their daughter's health was much better than before; she will stay in the house only a few years more; they felt the contractors were proposing to charge too much; and finally, they questioned the accuracy of the mold tests.

Since the recommended renovations were not going to be carried out, House 6 was dropped from the monitoring. Unfortunately, this meant one house less out of the pool of six houses. There were, however, insights learned about people's priorities, particularly as they relate to health.

House 8 (Control House)

Health History

The 40 year old female homeowner had asthma. She had lived in the house with her husband and son for 16 years. She had been diagnosed with asthma five years earlier. The frequency of her asthma was less predictable than in the past.

During an asthma attack, she experienced coughing, wheezing, breathlessness and chest tightness. Her symptoms between asthma attacks were shallow breathing and chest tightness.

Her asthma was generally worse in the winter and spring and was worst in the months of September (ragweed), February (very cold weather) and April. Colds, pollen, molds, hot humid weather, cold winter air, polluted air, cigarette smoke, scents, dust, fatigue, physical exertion and feathers made her breathing worse. Her symptoms were usually worse at nights and her asthma was worse at home in the basement or outdoors if it was windy. She felt better outside only on nice, warm and non-windy days. She went to the basement several times a day. She usually had a harder time breathing in the basement especially in the laundry area.

At the time of the visit, Virginia Salares and John VandeKleut observed the deterioration in the homeowner's breathing after spending about half an hour in the basement. As a result of the discomfort, she had to take her medication. During the inspection, the basement smelled moldy. Mold was visible in some areas of the laundry room.

Summary of Renovation Work

Some stored materials, primarily cardboard boxes, were removed from the basement. Wallpaper in a small area on the main floor was stripped.

The analysis of a dust sample vacuumed from the basement area in September 1998 showed the presence of *Penicillium viridicatum* and *Aspergillus versicolor*. Air samples gave higher mold counts in the laundry/shop area compared to the other basement areas.

Health Observations during Study Period

There was no difference in the frequency of asthma, severity of symptoms or medication. The homeowner diligently took peak flow measurements during this period (see next section). The measurements paralleled her reports — the basement made her feel ill.

House 10 (Control House)

Health History (before renovation)

The female homeowner had asthma. At the outset of the study, she had lived in the house with her husband for 50 years. She was 74 years old and had been diagnosed with asthma five years earlier although she believed she had it before that time.

She did not know all the triggers of her asthma, but she reacted to dust, cigarette smoke, wood smoke, chemicals, insect bites and some foods. She felt better outside in fresh air.

This home had a major oil spill in the basement and significant levels of mold, particularly in the basement.

Summary of Renovation Work

The soil in the area of the furnace where an oil spill had occurred was excavated and discarded. Although this addressed the chemical contamination it did not address the extensive mold problem also evident in the house. No tests for molds were conducted in this house.

Health Observations during Study Period

Her coughing asthma was ongoing. It flared up when she was aggravated. She believed she was aggravated by more things — that she had become more sensitive.

Her asthma attacks became more frequent and her symptoms became worse than in previous years. She had a harder time breathing than before. She had more colds in the 1997/98 winter compared to previous years. She had less energy than before. The types and dosages of medication had not changed. She felt the same in her basement and she was able to stay in her basement for the same length of time as before.

House 12 (Control House)

Health History (before renovation)

The female homeowner had asthma. At the outset of the study, she had lived in the house with her husband and children for two years. She was 34 years old and a nurse and had been diagnosed with asthma 10 to 12 years earlier. Her asthma deteriorated significantly in the previous year to the point where she had to quit working. Her 7 year old daughter was diagnosed with asthma about five years ago.

Her asthma was worse in the summer and winter. Extreme temperatures, either very hot or very cold, made her breathing worse. Cigarette smoke and cleaning products also triggered her asthma. She experienced wheezing, shortness of breath, coughing, and chest tightness during an asthma attack.

Summary of Renovation Work

No renovations were done in this house. No tests for molds were conducted in this house.

Health Observations during Study Period

She underwent surgery for a reflux problem in November, 1997. She felt her asthma improved after the surgery. Following her surgery, she required only four increases in her medication.

Her asthma attacks were less frequent than in previous years and she was taking less medication than before. She reported that the symptoms associated with her asthma, namely, coughing, wheezing, breathlessness, chest tightness, sore throat and mucus in her throat had improved. She found no difference in her breathing (when she was not having an asthma attack) inside her house during the period of the study. She had as many colds as in previous years.

There was no difference in her energy level or in her level of comfort or ability to notice odours inside the house. She developed a pain in her right hip and was diagnosed with O.A. (osteoarthritis) from long-term steroid use. She believed she would need hip surgery soon.

In the spring of 1998, heavy rains caused flooding in her basement. Her asthma became worse.

House 13 (Control House)

Health History (before renovation)

The male homeowner had asthma. At the outset of the study, he had lived in the house with his wife and young son for six months. His symptoms had become worse after he moved into the house.

He noticed his breathing problems were worse when the heating system was turned on and also when the air conditioning was on. The basement was the worst part of the house for him.

Summary of Renovation Work

Lots of stored materials, including DDT from the previous occupants, were discarded.

The analysis of a dust sample vacuumed from the basement area in September 1998 showed the presence of *Aspergillus fumigatus*, *Aspergillus versicolor* and *Penicillium viridicatum*. Air samples showed higher mold counts in the finished room in the basement relative to the utility room and the living room.

Health Observations during Study Period

He confirmed that, as a participant in this study in which he had to take peak flow readings, he had asthma attacks whenever he took measurements in the basement. His asthma was noticeably worsened after spending an hour or more in the basement.

He felt the frequency of his asthma attacks was the same or less frequent than in previous years. Because the 1997/98 winter was milder, the furnace was not turned on as much. Similarly, the air conditioning was not needed as before. He found no difference in how he breathed. He had as many colds in the 1997/98 winter as in previous years. He had a persistent cough between April and the summer of 1998. He was taking more medication than before. In the summer of 1998, he was prescribed *Flovent 250* daily. The salbutamol was taken only as needed on rare occasions.

At the end of the study period, the homeowner gutted the basement, had it cleaned with bleach and the joist spaces insulated with extruded polystyrene and sealed.

11. HEALTH MONITORING BEFORE AND AFTER RENOVATION: PEAK FLOW MEASUREMENTS

Of the six participating families, data was not returned by two participants (occupants with asthma in Houses 2 and 6). In House 3, the daughter was too young to take the peak flow measurements, and the mother did not have asthma at the beginning of the study. Three of the four asthma sufferers who were acting as controls for the project took peak flow measurements. Two carried out the measurements in the basement.

Results of Daily Peak Flow Measurements

There were large variations of readings on a day-to-day basis. The ranges in the peak expiratory flow rates (PERF's) taken by the occupant with asthma in the homes contributing data are shown in Table 11.1. These measurements were taken over the timeframe of the study.

The participants observed that the peak flow readings did not reflect how they felt at the time of the measurements. At times when they were feeling wheezy and ill, the peak flow readings did not register any significant difference to the times when they were feeling better.

On the occasion when the occupant with asthma in House 5 attempted to take peak flow measurements in the basement, she became quite uncomfortable almost immediately, and she could not continue to stay in the basement. The peak flow meter did not register a change.

The occupant of House 4 reported that her PEFR hardly changed even after taking her medication.

Table 11.1
PERF s as Measured by Occupants with Asthma

	PEFRs L/min
Occupant of House 1 with asthma	375 - 575
Occupant of House 4 with asthma	220 - 330
Occupant of House 5 with asthma	300 - 340
Occupant of House 8 with asthma	350 - 470
Occupant of House 12 with asthma	270 - 500
Occupant of House 13 with asthma	480 - 600

The three controls, on the other hand, all registered an increase in PEFR readings after taking their medication.

Results of Peak Flow Measurements in Basement

The basements of Houses 1, 4 and 5 were much too moldy for the occupants with asthma to tolerate. They did not conduct the PEFR measurements in the basement.

Two of the controls took measurements diligently. The occupant of House 8 with asthma did the breathing test in the basement on six different occasions. Her initial PEFR differed each time — the volume reading appeared to reflect how well she was feeling on that particular day and time. In each trial, the readings decreased as she stayed in the basement and increased again after she went up the stairs. The maximum reduction in her PEFR was 50 L/min within approximately half an hour of going in the basement. Staying in the basement for another half hour did not depress the volume readings any further. She was able to regain her initial PEFR an hour after returning upstairs.

These results were surprisingly consistent. There were two explanations. The individual had been taking peak flow measurement for four years and had, in all likelihood, learned the technique exceedingly well. Secondly, the upper floor of her house was almost always well ventilated with open windows and had good air quality, whereas the basement had a mold problem and was not ventilated at all. Consequently, the difference in air quality between the upstairs and the basement was marked.

The occupant of House 13 took measurements in the basement six times. Each time, he became wheezy and experienced asthma symptoms within an hour of being in the basement. The volume readings decreased as he stayed downstairs and increased again when he returned to the main floor. However, the magnitude of the changes and the pattern were not as marked as the actual symptoms he experienced.

12. SUMMARY OF FINDINGS FROM FIVE STUDY HOUSES

Table 12.1
Summary of Findings From Five Study Houses

House No.	1	2	3	4	5
Health Problems	48 yr old female – asthma +	44 yr old male – asthma	child – asthma, mother – allergies	38 yr old female – asthma	39 yr old female – asthma, child asthma
Allergies to	dust, molds, chemicals, etc.	perfume, dust, etc.	food & environment	pesticides, coal/oil dust, etc.	dust, molds, grasses, smoke, etc.
Age & Type of House	1930s, 3-storey detached brick, F/A oil + electric baseboard heat	1980s, detached bungalow, brick & wood, electric baseboard heat	1955, detached brick bungalow, F/A electric heat	before 1930, 2-storey, semi-detached brick, F/A heat	1920, 3-storey masonry, fireplace, gas hydronic heat
Major Concerns Identified Through Inspection	• molds in basement • upstairs carpets • lack of ventilation • water infiltration – basement walls	• severe molds • lack of ventilation	• molds in basement • lack of ventilation • water leaks • contaminant sources	• molds • dampness in basement • dirt in ductwork	• molds in basement • lack of ventilation
Problem Areas Identified Through Testing Before Reno	• basement • master bedroom	• basement, finished & unfinished areas • dining room • master bedroom • main floor	• basement, finished & unfinished areas • child's bedroom • master bedroom • main floor	• basement • main floor • second floor bath • second floor	• basement • third floor bedroom • dining room • second floor bedroom
Required Remediation	• clean up clutter in basement • clean walls & ceiling with bleach, paint floor • foam penetrations through walls • remove carpeting • seal 3rd floor wood • excavate exterior and install drainage • install HRV	• gut basement • clean all surfaces with bleach • excavate around exterior of house, install drainage • replace HRV	• fix sewer drain pipe • gut, clean and seal basement • clean up & repairs • clean mold from window frames • remove dining room carpet • install HRV • regrade yard	• clean up basement • vent dryer outside • foam all penetrations in walls & floors • airseal and clean ducts • install HRV	• gut and clean basement • clean or replace damaged hardwood floor • install HRV • clean up and minor repairs • clear and clean up third floor room • regrade yard • replace gas stove
Remedial Work Carried Out	• thoroughly cleaned basement • bleached basement • foamed wall penetrations • removed carpeting, installed hardwood • sealed 3rd floor • installed HRV • installed central air conditioning (not recommended)	• only partially gutted basement • cleaned surfaces with bleach	• fixed sewer problem • gutted, cleaned, sealed and painted basement • carried out extensive clean up and repairs • cleaned mold from window frames • removed carpet from dining room • installed HRV • excavated exterior, installed drainage and regraded yard	• cleaned basement • removed bathroom walls and fixtures in basement • bleached and limewashed basement • vented dryer outside • foamed penetrations in walls & floors • airsealed and cleaned ducts	• gutted and cleaned basement • cleaned damaged hardwood floor • installed ERV • installed central air conditioning • carried out some clean up and minor repairs • rebuilt cold cellar in basement (not recommended)

Table 12.1
Summary of Findings From Five Study Houses (Continued)

House No.	1	2	3	4	5
Renovation Timeframe	July & August 1997	continuing	September & October, December 1997	July & August 1997	July & August 1997
Required Remedial Work NOT Carried Out	• excavate & install drainage around exterior of house	• removal of some wood framing and brick wall in basement • excavate & install drainage around exterior of house • replace HRV		• install HRV	• clear and clean up third floor room • damaged hardwood floor cleaned not replaced • regrade yard • replace gas stove
Problem Areas Identified After Completing Reno Work	• basement – both north and south ends • mold growing on basement walls	• main floor living areas • bedrooms • basement	• child's previous bedroom • basement	• basement – both north and south ends • second floor bath	• basement • basement – antique desk • dining room floor at radiator
Health Immediately After Initial Renovation Completed	• not improved	• aggravation of asthma while doing clean up without protection	• not much improvement for mother, some improvement for daughter	• improved	• no immediate improvement but after a month or so a steady improvement
Further Remedial Work Carried Out	• sealed crawlspace from basement – possible source of mold spores		• repeated basement cleaning • filled top of concrete block cores in basement wall to seal mold in cores • installed new basement windows	• further cleaned basement and second floor bathroom	• rebleached floor and plans to replace floor in dining room • disposed of antique desk in basement
Problem Areas Identified After Doing Further Work	• crawlspace • basement walls		• none – house was clean	• main floor – books and sofa – source of molds? • basement • rotting joists	• smell of mold from cold cellar
Additional Work				• disposed of living room sofa	• unblocked fan and vent in cold cellar
Further Problem Areas				• dehumidification necessary until foundation sealed and insulated on outside	• contamination – cold cellar & east basement • toxic chemicals stored in house • dehumidification necessary until foundation sealed & insulated on outside
Health At Completion of Study	• not improved	• not improved – work not completed	• very noticeable improvement for mother and daughter	• dramatically improved – off asthma medication	• mother – marked improvement, son & daughter – significant improvement

13. OBSERVATIONS AND CONCLUSIONS

General

1. Mold was the predominant indoor air quality problem identified in the houses studied under the project.

2. Inspecting the houses using the procedure developed for the Residential IAQ Investigator program identified both the sources of the molds and the remedial measures.

3. Qualitative estimates of the severity of the mold problems in the houses were made during the investigation based on odours, visible molds and indications of moisture. In most cases, the mold tests confirmed the qualitative assessments and identified the toxigenic mold species.

4. Generally, the occupants were conditioned to the mold odours in their houses and had poor understanding of the significance of the molds.

5. In one house, a distinct moldy smell was noticed upon entering and a strong smell of mold was detected in the basement. However, during the inspection, no visible evidence of mold or signs of moisture could be seen. Air sampling and swab samples confirmed a serious mold problem.

6. Many molds, other than the typical outdoor molds, were found in all six houses. Most air samples failed the Pass/Fail criteria for contamination due to molds.

7. In all cases, the basements were the most significant sources of molds. Crawlspaces with earth floor were potentially high sources of mold contaminants. There were additional localized sources in some of the houses.

8. The remedial work resulted in a significant reduction in the level of molds and fungi detected through the testing. In four of the five houses where the remedial work was carried out, however, some toxigenic fungi continued to be identified after the clean up and renovation work. Samples failed the pass/fail criteria for mold.

9. Furnishings had to be de-contaminated in the same way as the building; otherwise, mold was re-introduced from those sources.

10. Pressure-treated wood, though chemically treated against mold or rot, was found to support the growth of toxigenic molds (House 2).

11. It was not always possible to identify all the sources of molds during one assessment. Removal of the strongest sources made identification of the secondary sources easier.

12. After the completion of the renovation and remedial work, a number of previously undetected molds were identified. This may have been the result of a number of factors including:
    - different time of year of testing,
    - dominant molds masking or suppressing other molds,
    - cleaning killed some molds but others grew as a result of the altered conditions.

13. In houses that were moldy for an extended period of time, or where the mold growth was invasive, the clean up had to be aggressive.

14. Recurrence of mold after clean up occurred when the moisture source was not corrected even when the occupants were vigilant in controlling moisture through the use of dehumidifiers.

15. Monitoring the house for molds before and after clean up provided a measure of the effectiveness of the clean up.

16. Re-testing should be done immediately after clean up and again at a later period.

17. Ventilation cannot be solely relied upon to solve indoor air problems. HRVs provided ventilation and controlled the growth of molds in the locations where ducts were installed.

18. The contractors who undertook the clean up required training. Some contractors did a more thorough job than others.

Specific to this Pilot Study

19. It was easy to find people with asthma whosuspected they had indoor air quality problems in their homes. It was more difficult to find homeowners who would spend money to undertake the required improvements to their houses.

20. Homeowners required knowledgeable advice to identify the indoor air quality concerns in their homes and to identify the steps needed to eliminate the mold problems. They also needed to have the work supervised for thoroughness and completeness.

21. A basic step required in all houses in this study involved discarding and de-contaminating materials stored in the basements. An accumulation of "stuff", particularly in the basement, provided more "food" for the mold and restricted air movement. Items piled in cooler basement corners were prone to mold growth.

22. The VOC tests were the least useful in this study. More information was obtained by identifying the sources of the chemical contaminants and removing them.

23. The tests for ergosterol were not particularly informative in this study. The exposure times or method of analysis require review.

24. Dust mite antigens did not show any obvious correlation with mold contamination or the reported symptoms of the occupants. Higher Der f 1 in the living room compared to the basement in two of the houses ruled out dust mites as the cause of the asthmatic occupants' aggravation of asthma in the basement.

25. In one house (House 3), extensive remedial work was carried out to control moisture entry into the basement. This house had markedly fresher air and passed the Pass/Fail criteria after the renovation. In three houses (Houses 1, 4 & 5), the basements were cleaned but moisture entry was not controlled. These houses had improved air immediately after the cleaning but failed the Pass/Fail criteria on subsequent re-testing. In one house (House 2), the cleaning was not properly carried out. Serious contamination persisted in this house.

26. The final monitoring was delayed until the participants had implemented as much of the recommended cleaning as possible. The re-tests were done several months after the major cleaning of the basements. It would have been useful to re-test immediately to determine the success of the clean up and to monitor again later.

27. The study showed that reductions in the mold contamination of the house resulted in positive benefits to the asthma patient — reduction in the frequency and severity of asthma and of medication.

    The control subjects (asthma patients whose houses were not renovated during the study period) did not show an improvement in their asthma during the study period.

28. Benefits other than respiratory were reported by the participants. These included greater comfort in the house. The occupants of House 3 reported less dizziness, less diarrhea, improved concentration and higher energy levels after the removal of the mold.

29. Improvements in the health of the occupants correlated with the improvements in air quality. The occupants of House 3, where remedial work was carried out to control water entry, experienced marked improvements to their health after the renovation. The occupants of Houses 4 and 5 reported marked improvements in their asthma the winter and summer after the renovation. The occupant of House 1 experienced no health improvement.

30. The improvement of the air quality in the house made the asthma more manageable for most of the participants.

31. Most of the participants in this study were genuinely interested in improving their health.

32. Homeowners, especially those with asthmatic family members, would benefit from information relating to the health effects of molds.

33. Participation in this study was a learning experience for the participants. In order to control moisture and molds, their house maintenance practices had to be modified.

34. Measures of peak expiratory flow rates (PEFRs) were not as sensitive a measure of the impact of the environment on the asthmatic individual as their actual reports were of how they felt.

35. The best monitor of the participant's health was the participant themselves. Symptom reports, feelings of well-being and changes in medication provided a detailed review of their health changes.

36. The after renovation monitoring period may take six to nine months after the renovation.

37. A study involving a larger number of houses would be useful. Future studies should emphasize the need to implement long-lasting solutions to mold problems. Only participants with a demonstrated commitment to completely carry out the recommended remedial work should be selected.

ENDNOTES

1 Drerup Armstrong Ltd, **A Survey of Problem Homes of the Environmentally Hypersensitive**, prepared for Canada Mortgage and Housing Corporation, Ottawa, May 1996.

2 Environmental Health Directorate, Health Protection Branch, Health and Welfare Canada, **Exposure Guidelines for Residential Indoor Air Quality**, A Report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health, Ottawa, 1989, p. 4.

3 ibid., p. 9.

4 Miller, J.D. et al., *Fungi and Fungal Products in Some Canadian Homes*, in **International Biodeterioration**, Vol. 24, 1988, p. 113.

5 Environmental Health Directorate, op.cit.

6 ibid., p. 107.

7 ibid., p. 117.

8 Author unknown, *Viable Fungi and Bacteria in Air, Bulk and Surface Samples*, p. 58.

9 Yang, Chin, *Problem Solving and Interpreting Results*, paper prepared as a contract consultant to the US Public Health Service, Federal Occupational Health, Region III, Philadelphia, Pennsylvania, 1995?, p. 2.

10 Some definitions are included in Appendix D of this report.

11 Tobin, R.S. et al., **Significance of Fungi in Indoor Air: Report of a Working Group**, Health and Welfare Canada, Working Group on Fungi and Indoor Air, Ottawa, March 1987, p. S1.

12 Yang, Chin, op.cit., p. 3.

13 David Miller, Private Communication, Fall 1998.

14 Yang, Chin, op.cit., p. 2.

15 Canada Mortgage and Housing Corporation, **Moldy Houses: Why They Are & Why We Care**, Ottawa, 1995.

16 Miller, J.D. et al., op.cit., p. 113.

17 Laboratory Report, John Hopkins University – Asthma and Allergy Center – Dermatology, Allergy and Clinical Immunology Reference Laboratory, Baltimore, Maryland, August 1997.

18 Forced air system turned off, opening to crawlspace sealed.

19 A high degree of confidence cannot be placed on this set of air samples because of the mold species found in the outdoor sample.